

(12) UK Patent Application (19) GB (11) 2 390 933 (13) A

(43) Date of A Publication 21.01.2004

(21) Application No: 0313691.8

(22) Date of Filing: 13.06.2003

(30) Priority Data:

(31) 2002208600 (32) 17.07.2002 (33) JP
(31) 2002354476 (32) 06.12.2002

(71) Applicant(s):

Alps Electric Co Ltd
(Incorporated in Japan)
1-7 Yukigaya, Otsuka-cho, Ota-ku, Tokyo,
Japan

(72) Inventor(s):

Kiyoshi Sato
Toshinori Watanabe
Toshihiro Kuriyama

(74) Agent and/or Address for Service:

Saunders & Dolleymore
9 Rickmansworth Road, WATFORD, Herts,
WD18 0JU, United Kingdom

(51) INT CL⁷:
G11B 5/31

(52) UK CL (Edition W):
G5R RMD RMMT

(56) Documents Cited:
US 6417990 B1
US 6191918 A
US 20010013505 A1

US 6259583 B1
US 6154346 A

(58) Field of Search:

UK CL (Edition V) G5R
INT CL⁷ G11B
Other: Online: EPODOC, WPI, PAJ

(54) Abstract Title: Thin film magnetic head having planarized layers

(57) A coil layer 35 is formed in a space surrounded by a lower core layer 29, a protruding layer 32 and a back gap layer 33, and the tops of the protruding layer, a coil insulating layer 36 and the back gap layer are planarized to a continuous flat surface. A lower magnetic pole layer 39, a gap layer 40, an upper magnetic pole layer 41 and an upper core layer 42 are formed on the flat surface. Since the lower magnetic pole layer, the gap layer, the upper magnetic pole layer and the upper core layer can be formed on the flat surface, the four layers can be precisely formed in a predetermined shape, and the track width Tw can be easily be set to a predetermined dimension by the width dimension of the upper magnetic pole layer at the surface facing the recording medium. Also, the magnetic path can be shortened to improve magnetic properties.

FIG. 1

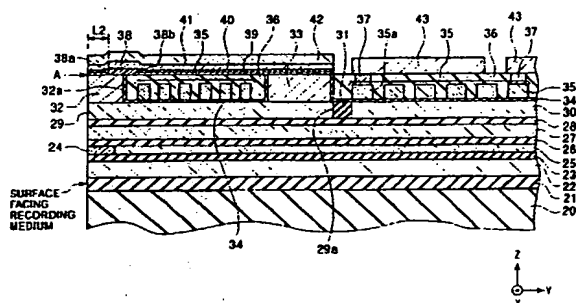




FIG. 5

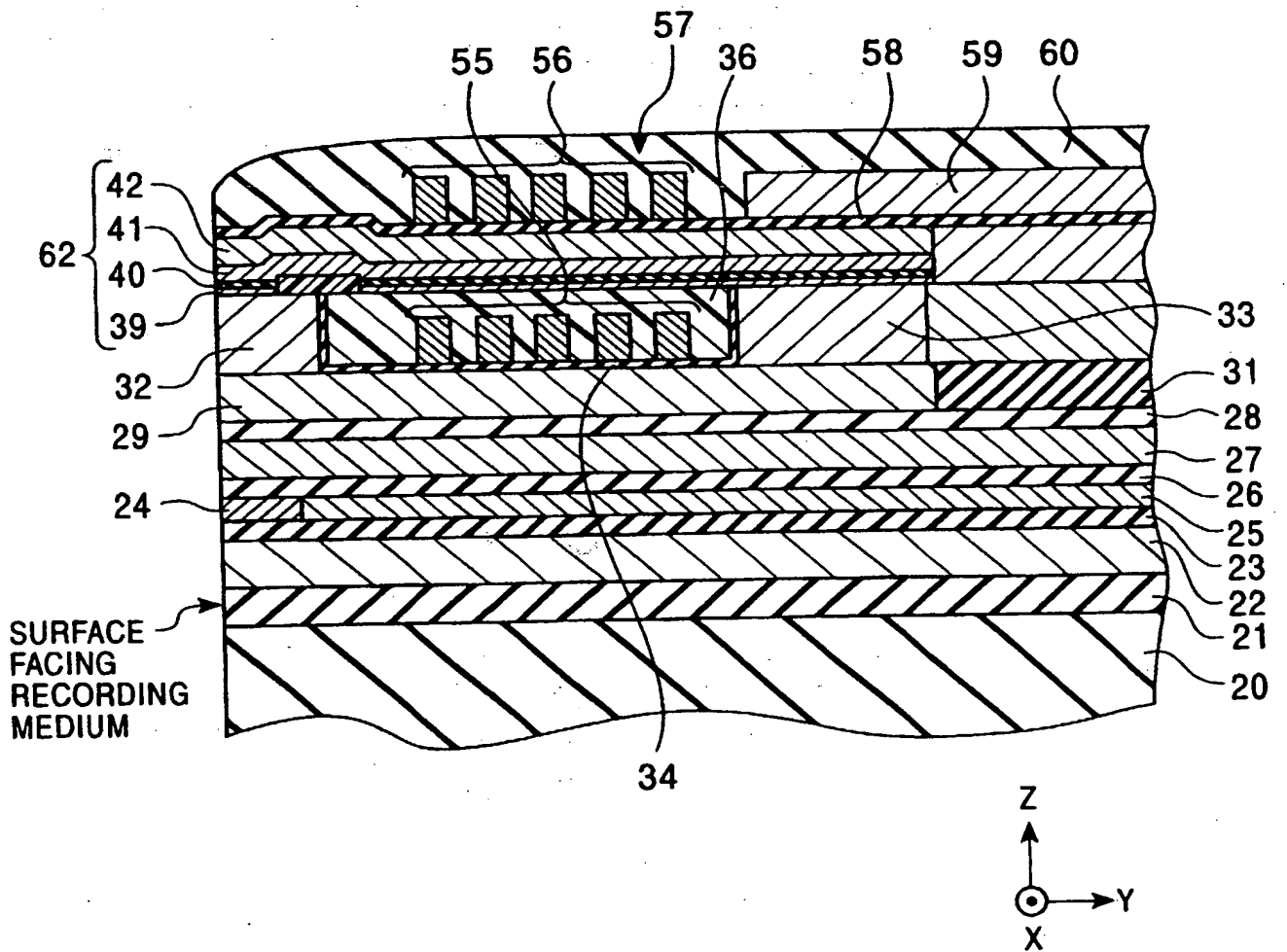


FIG. 6

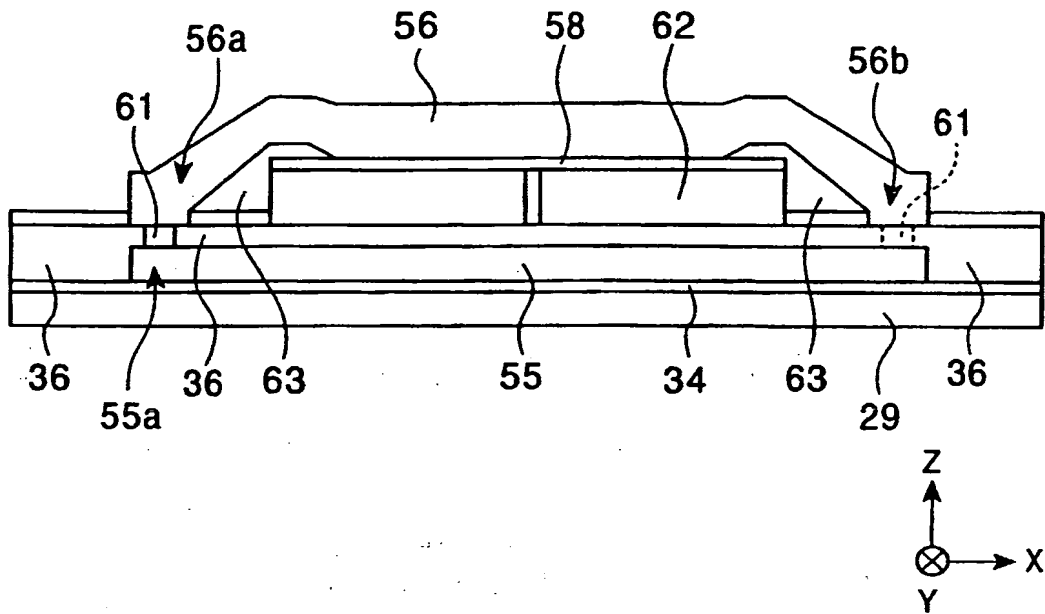


FIG. 7

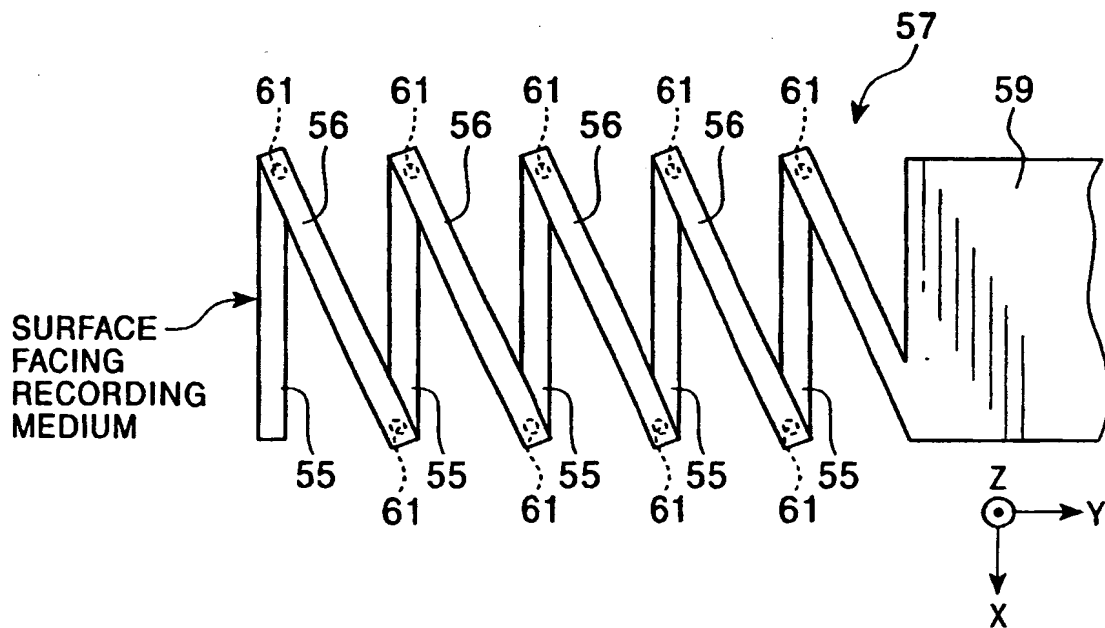


FIG. 8

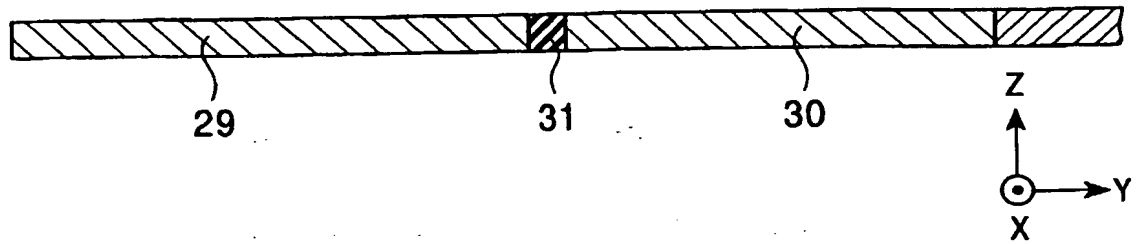


FIG. 9

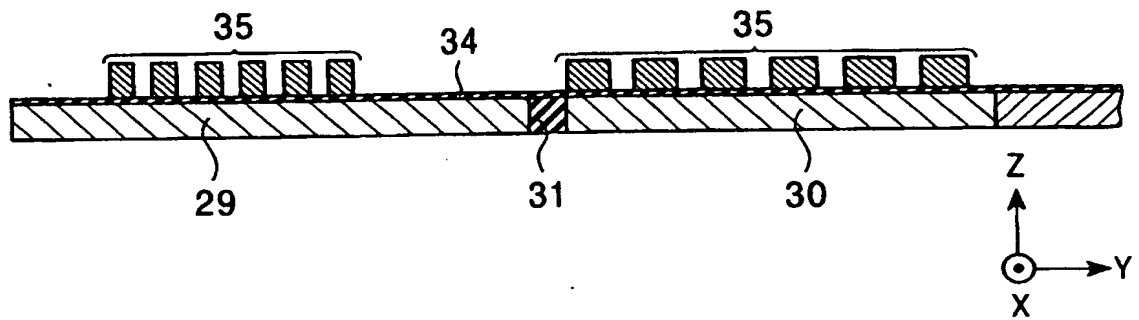


FIG. 10

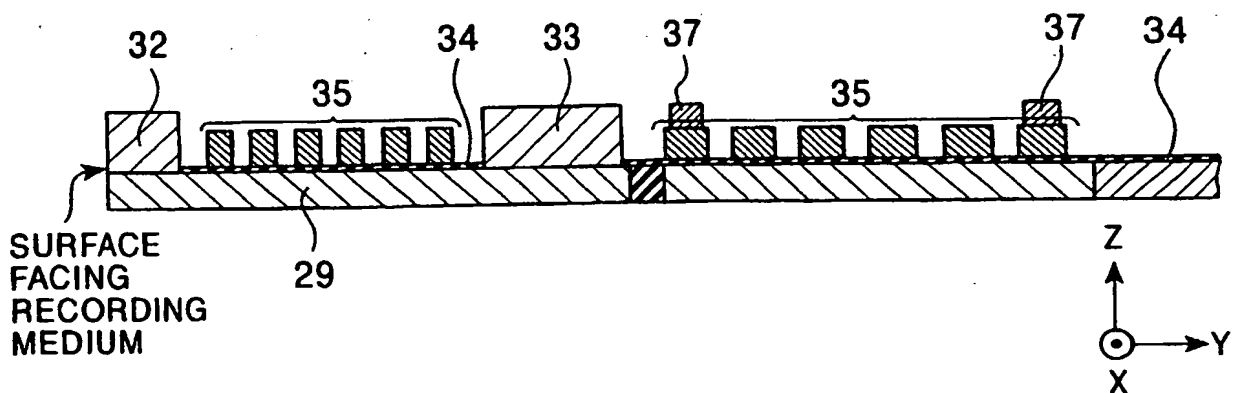


FIG. 11

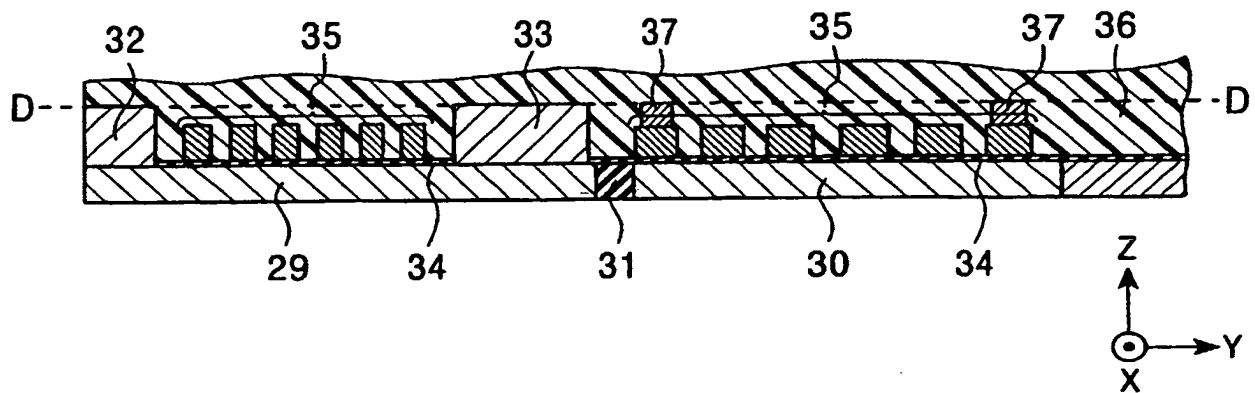


FIG. 12

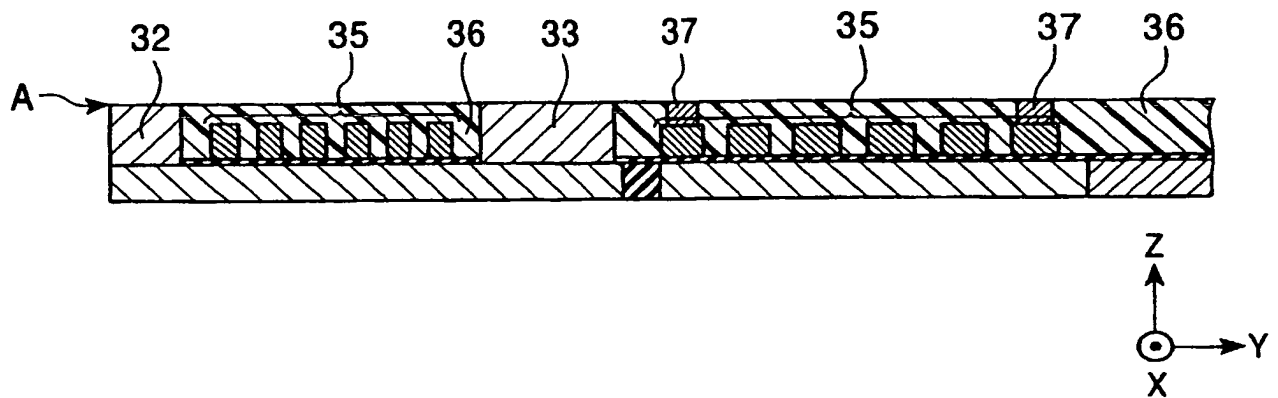


FIG. 13

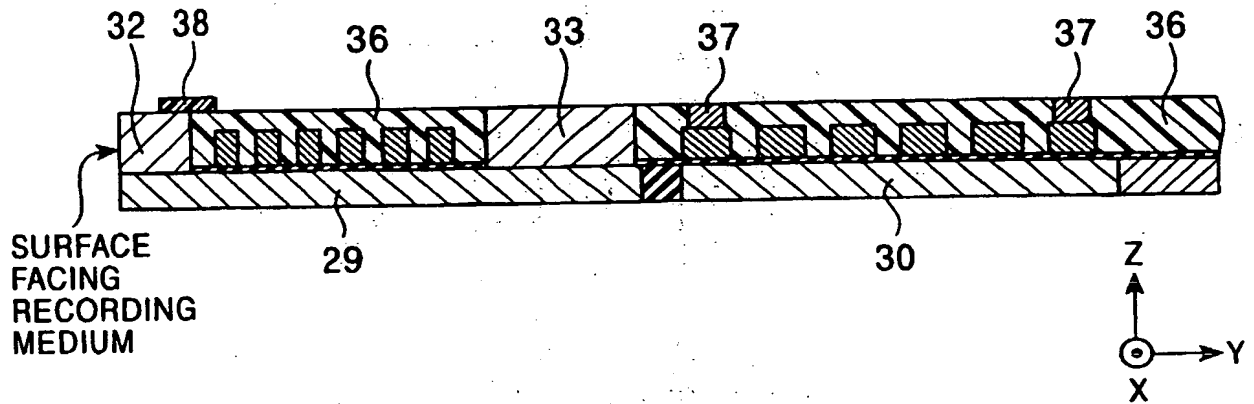


FIG. 14

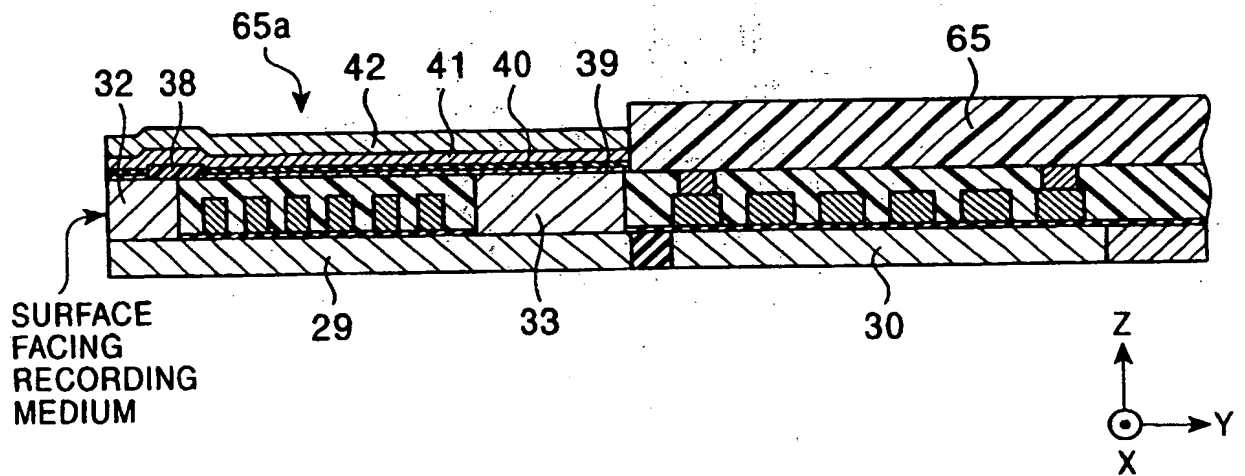


FIG. 16

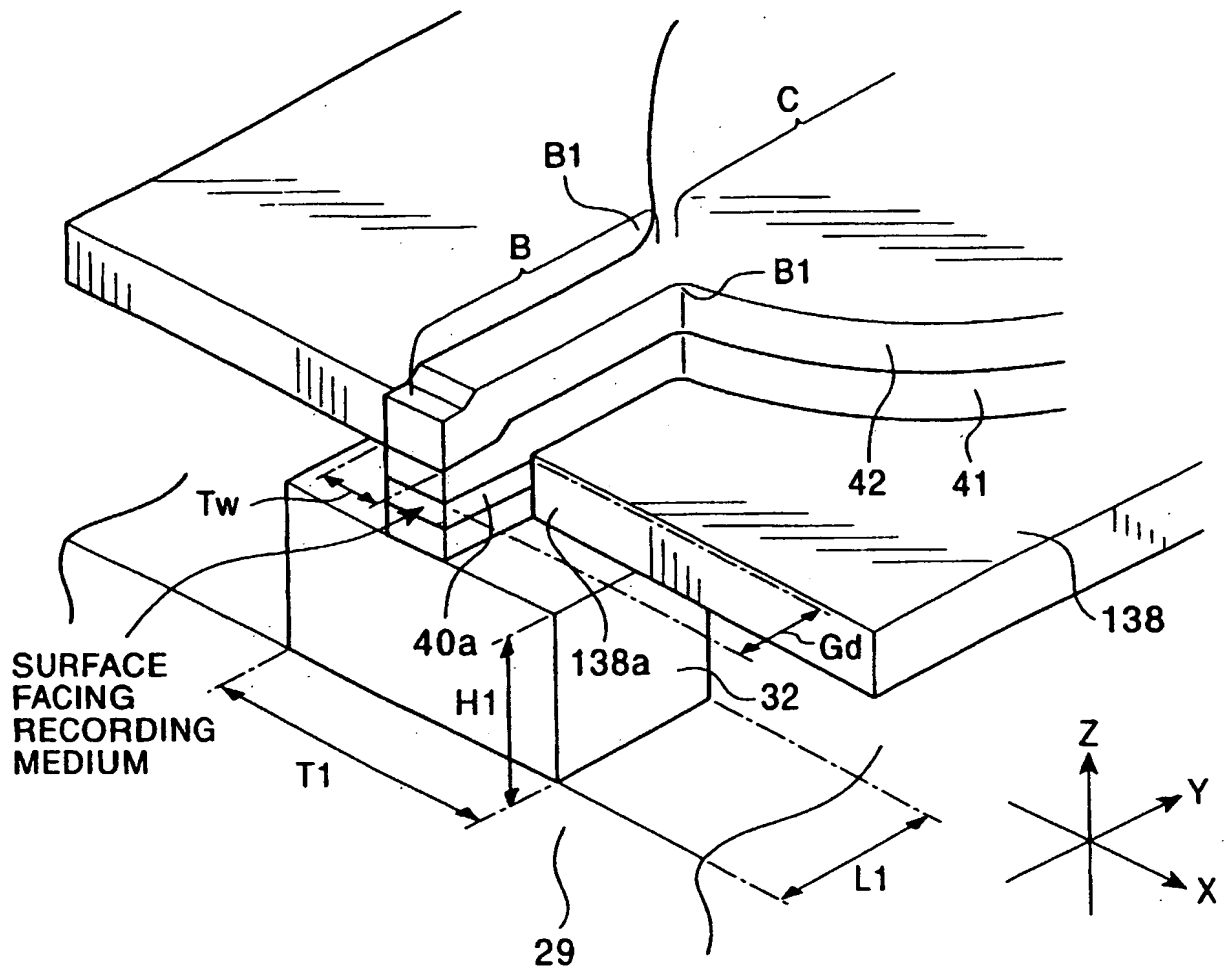
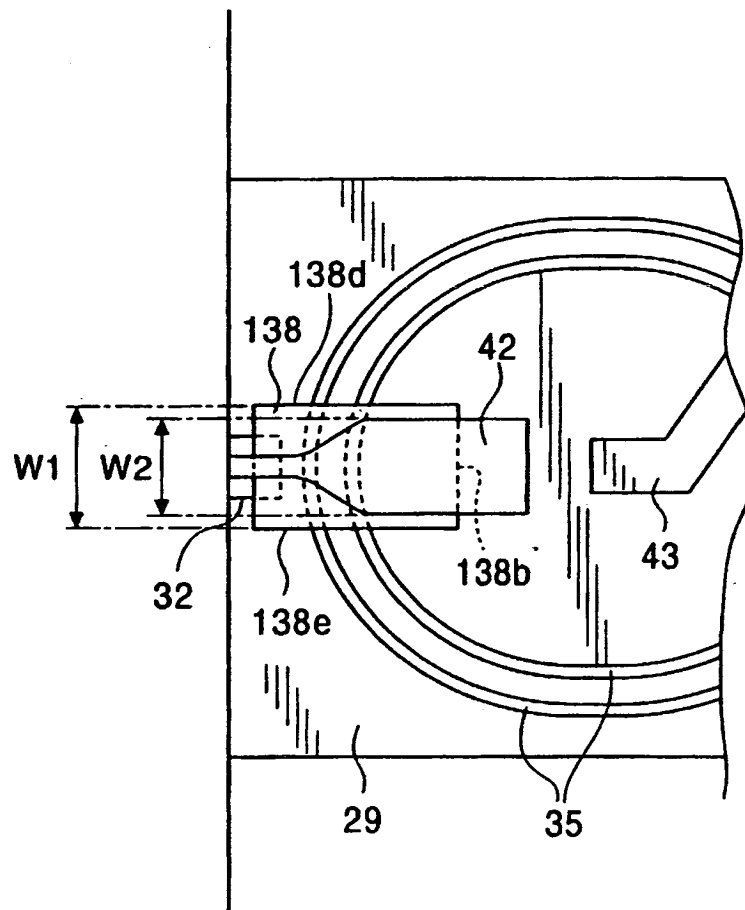
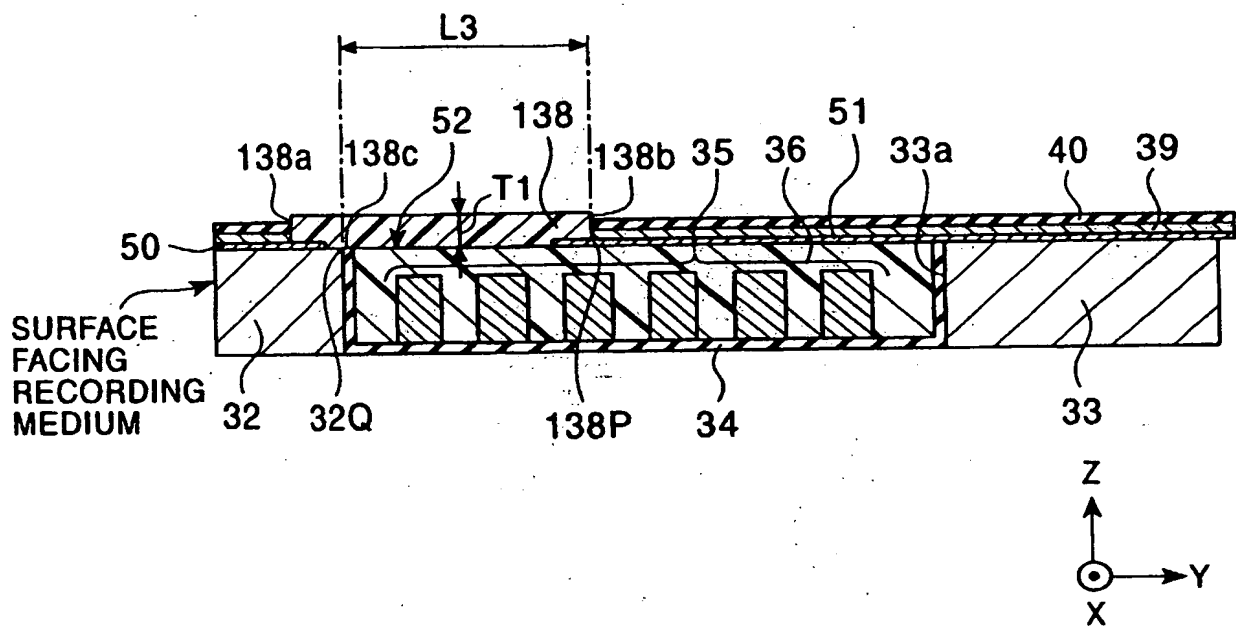


FIG. 17



P



29

FIG. 21

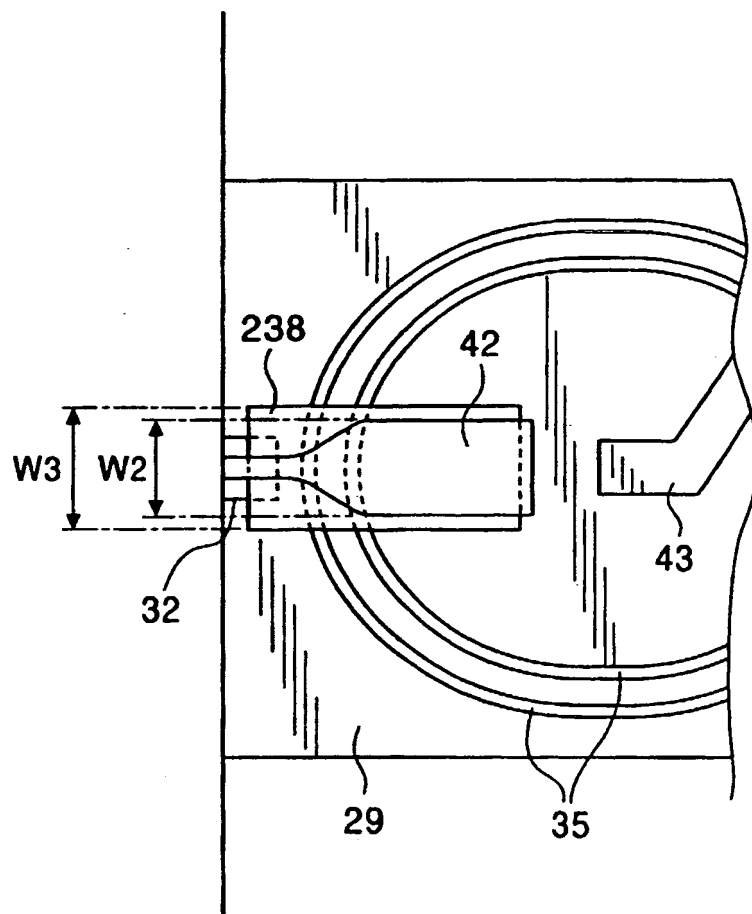




FIG. 23

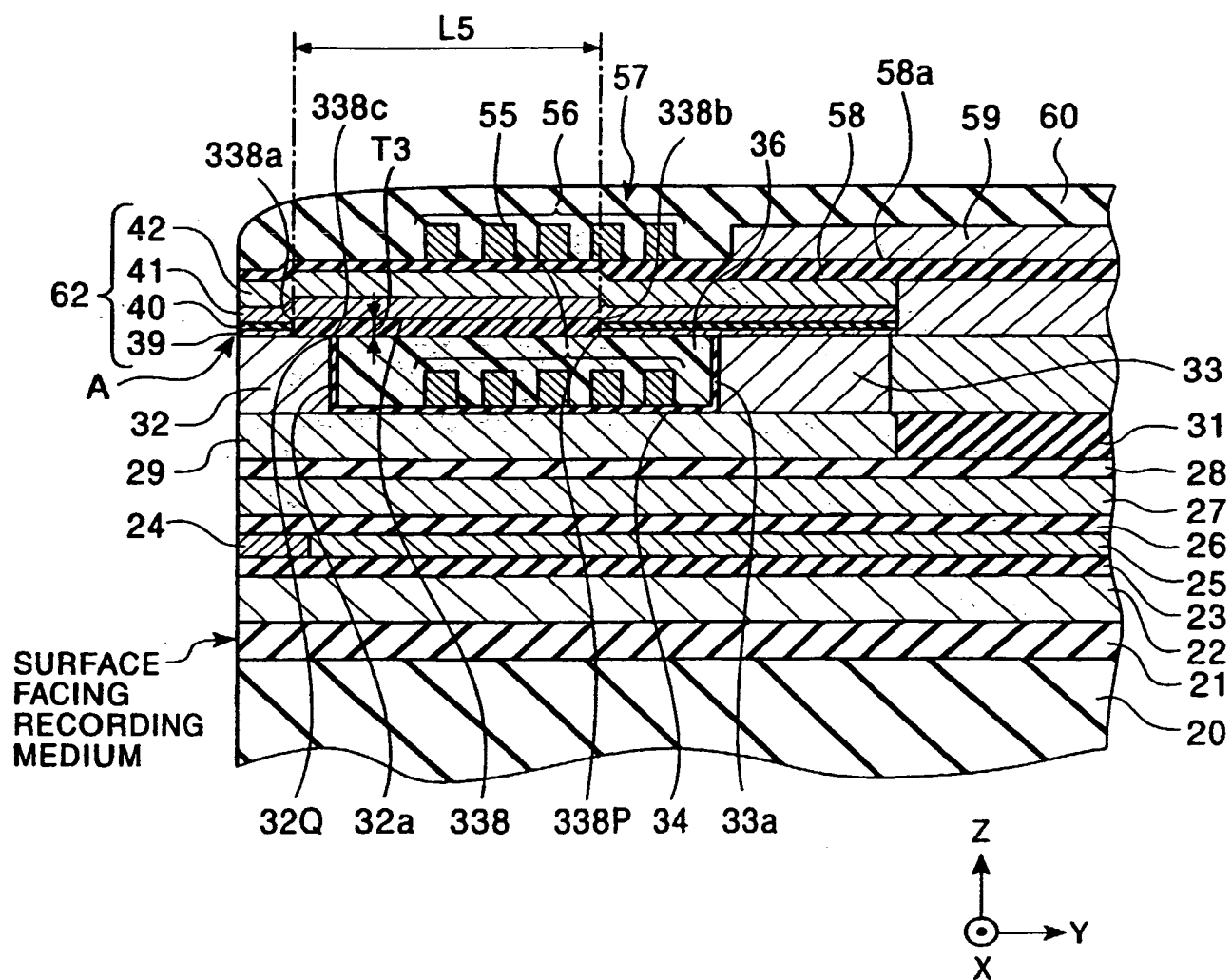


FIG. 24

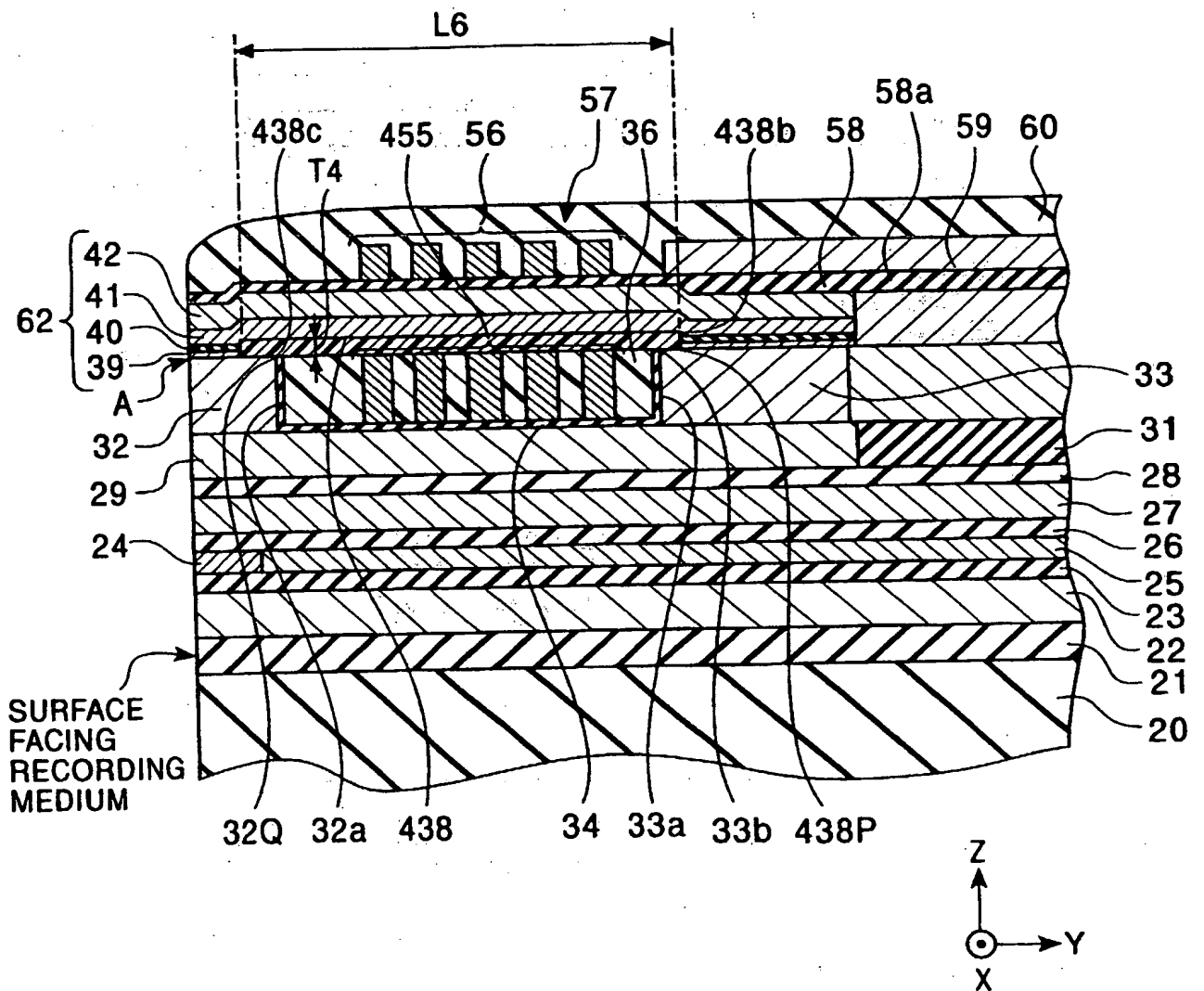


FIG. 25
PRIOR ART

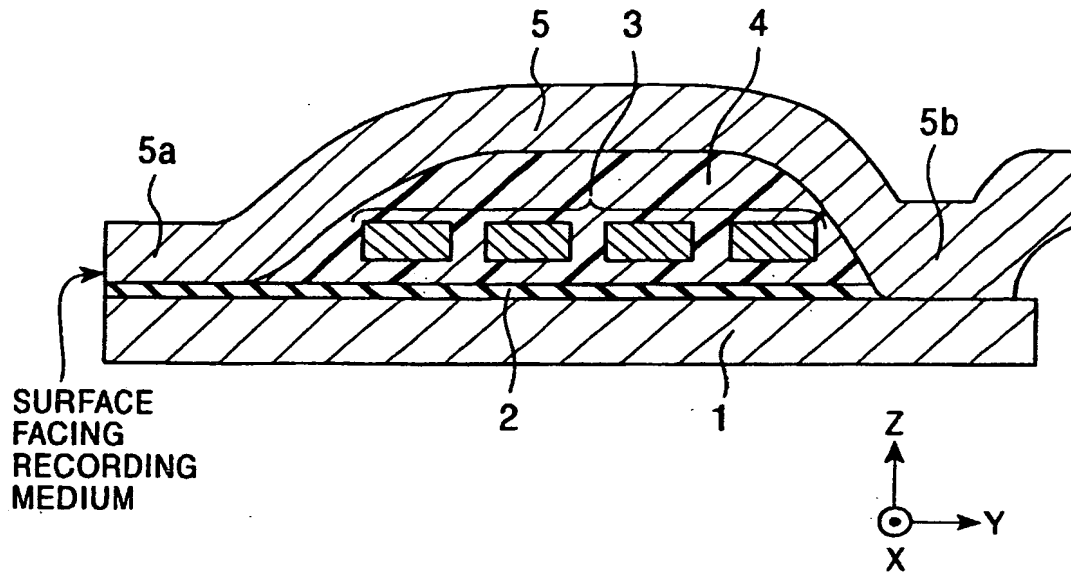


FIG. 26
PRIOR ART

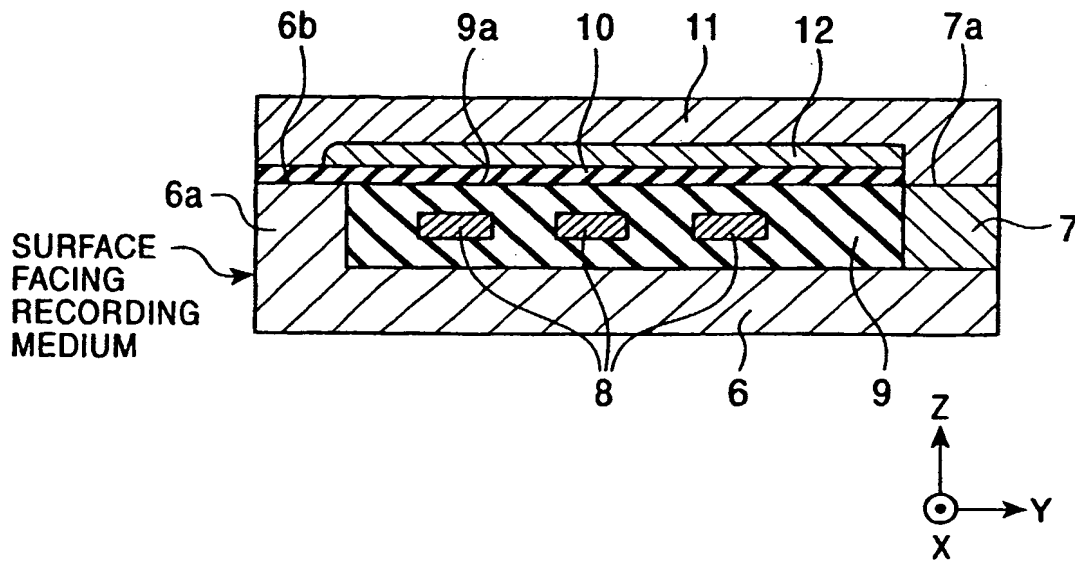


FIG. 27
PRIOR ART

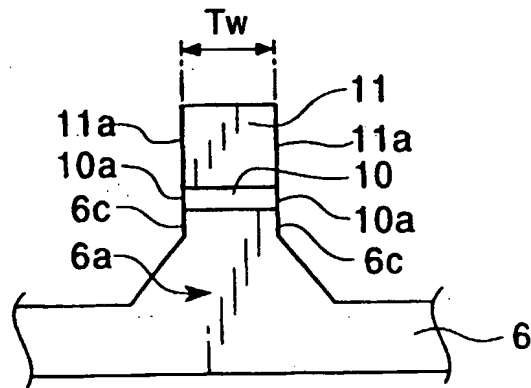
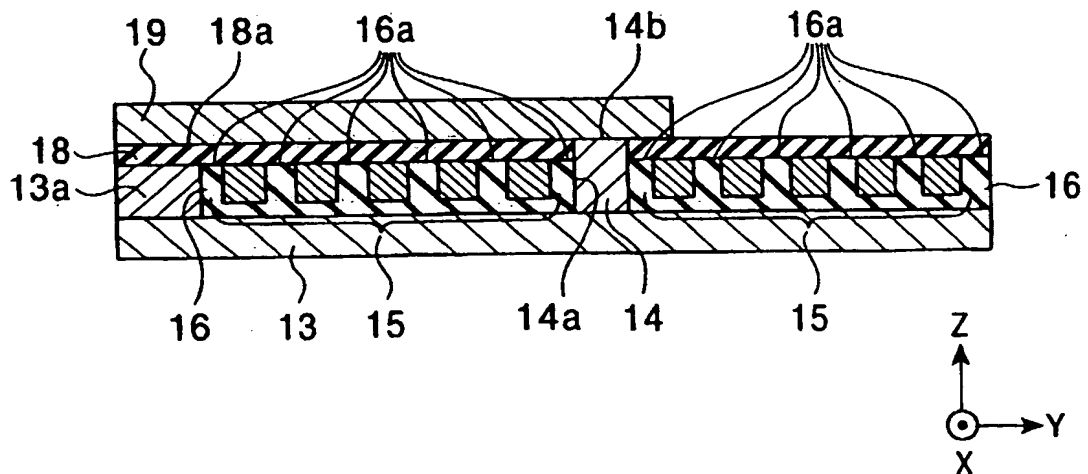


FIG. 28
PRIOR ART



THIN FILM MAGNETIC HEAD AND METHOD OF MANUFACTURING THE SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

5 The present invention relates to a recording thin film magnetic head used for, for example, a floating magnetic head and the like. Particularly, the present invention relates to a thin film magnetic head which is adaptable to a narrower track, and in which a track width can be precisely formed to
10 a predetermined dimension, a magnetic path can be shortened, and a leakage of a magnetic flux can be suppressed to improve recording characteristics, and a method of manufacturing the thin film magnetic head.

2. Description of the Related Art

15 Fig. 25 is a longitudinal sectional view showing an example of conventional thin film magnetic heads, in which the leftmost surface shown in parallel to a X-Z surface on the left side of the drawing is a "surface facing a recording medium". In Fig. 25, the X direction coincides with the
20 track width direction, the Y direction coincides with the height direction, and the Z direction coincides with the movement direction of a magnetic recording medium such as a hard disk or the like.

 In Fig. 25, reference numeral 1 denotes a lower core
25 layer made of a NiFe alloy, and reference numeral 2 denotes a gap layer made of Al_2O_3 or the like and formed on the lower core layer 1. As shown in Fig. 25, a coil layer 3 made of Cu is formed on the gap layer 2 and coated with an organic

insulating layer 4 made of resist or the like. Also, an upper core layer 5 made of a NiFe alloy or the like is formed on the organic insulating layer 4, the front end 5a of the upper core layer 5 facing the lower core layer 1 with the gap layer 2 provided therebetween near the surface facing the recording medium, and the base end 5b being formed in direct contact with a rear portion of the lower core layer 1 in the height direction.

Fig. 26 is a longitudinal sectional view of another example of conventional thin film magnetic heads, and Fig. 27 is a front view of the thin film magnetic head shown in Fig. 26. In Fig. 26, the surface shown on the left side of the drawing is a "surface facing a recording medium".

In Fig. 26, reference numeral 6 denotes a lower core layer which comprises a protrusion 6a protruding toward an upper core layer (the Z direction shown in the drawing) near the side facing the recording medium. As shown in Fig. 26, a back gap layer 7 made of a magnetic material is formed on a rear portion of the lower core layer 6 in the height direction (the Y direction), and a coil layer 8 is partially disposed between the protrusion 6a and the back gap layer 7. The coil layer 8 is covered with an insulating layer 9, and the top 6b of the protrusion 6a, the top 9a of the insulating layer 9 and the top 7a of the back gap layer 7 are planarized.

As shown in Fig. 26, a gap layer 10 made of Al_2O_3 or the like is formed to extend from the top 6b of the protrusion 6a to the top 9a of the insulating layer 9, and a nonmagnetic layer 12 is formed on the gap layer 10 to extend from a

position at a predetermined distance from the surface facing the recording medium in the height direction. Furthermore, an upper core layer 11 is formed over the gap layer 10, the nonmagnetic layer 12 and the back gap layer 7.

5 Fig. 28 is a longitudinal sectional view showing a further example of conventional thin film magnetic heads. In Fig. 28, the surface shown on the left side of the drawing is a "surface facing a recording medium".

10 In Fig. 28, reference numeral 13 denotes a lower core layer which comprises a protrusion 13a protruding toward an upper core layer (the Z direction shown in the drawing) near the surface facing the recording medium. As shown in Fig. 28, a back gap layer 14 made of a magnetic material is formed on a rear portion of the lower core layer 13 in the height
15 direction (the Y direction), and a coil layer 15 is partially disposed between the protrusion 13a and the back gap layer 14. The coil layer 15 is covered with an insulating layer 16, and the top 13b of the protrusion 13a and the top 16a of the insulating layer 16 are planarized.

20 As shown in Fig. 28, a gap layer 18 made of, for example, Al_2O_3 or the like is formed on the top 13b of the protrusion 13a and the top 16a of the insulating layer 16 to extend from the surface facing the recording medium to the front end 14a of the back gap layer 14, and the top 18a of the gap layer 18
25 and the top 14b of the back gap layer 14 are planarized.

Furthermore, an upper core layer 19 is formed over the top 18a of the gap layer 18 and the top 14b of the back gap layer 14.

These thin film magnetic heads are disclosed the following patent documents.

[Patent document 1]

Japanese Unexamined Patent Application Publication No.
5 2001-319311

[Patent document 2]

Japanese Unexamined Patent Application Publication No.
2001-250203

In recent years, the miniaturization of a thin film
10 magnetic head has been advanced, and the operation speed of a
magnetic head has been improved with increases in the
recording density and frequency, and thus the thin film
magnetic head is required to have severer characteristics.

In the thin film magnetic head, the width dimension of
15 the front end 5a of the upper core layer 5 at the surface
facing the recording medium is referred to as a "track width
Tw", and the width dimension decreases as the recording
density increases.

However, when the organic insulating layer 4 formed to
20 cover the coil layer 3 rises from the gap layer 2, as shown
in Fig. 25, the resist used for patterning the upper core
layer 5 is influenced by irregular reflection in development,
and thus the upper core layer 5 cannot be formed in a
predetermined shape, thereby easily increasing the track
25 width Tw.

The thin film magnetic head shown in Fig. 25 is required
to have a low thermal expansion coefficient. If a thin film
magnetic head has a high thermal expansion coefficient, the

thin film magnetic head easily causes a problem of thermal deformation in driving, particularly, a problem in which the gap layer 2 or the like projects from the surface facing the recording medium. The distance from the surface facing the recording medium (not shown) to the surface of the recording medium is referred to as a "spacing", and the spacing is further decreased for realizing a higher recording density. However, the problem of projecting the gap layer 2 or the like causes a problem of collision of the thin film magnetic head with the recording medium due to the narrow spacing during driving.

The thin film magnetic head shown in Fig. 25 comprises the organic insulating layer 4 made of resist or the like, for covering the coil layer 3. Since the organic insulating layer 4 has a higher thermal expansion coefficient than those of the other layers, the organic insulating layer 4 thermally expands during driving of the thin film magnetic head, and thus the gap layer 2 easily projects due to the expansion.

In the thin film magnetic head shown in Fig. 25, the magnetic path extending from the upper core layer 5 to the lower core layer 1 is long because the organic insulating layer 4 rises from the gap layer 2. Therefore, the coil layer 3 is required to have a certain turn number for improving the flux efficiency, and thus the coil resistance cannot be decreased to make the problem of projection more significant.

In the thin film magnetic head shown in Fig. 26, the coil layer 8 is buried in the space formed by the lower core

layer 6, the protrusion 6a and the back gap layer 7, and thus the thickness of a layer (the nonmagnetic layer 12) rising from the gap layer 10 is smaller than that in the thin film magnetic head shown in Fig. 25, thereby facilitating the precise formation of the upper core layer 11 in comparison to the thin film magnetic head shown in Fig. 25. However, the upper core layer 11 is not formed on a completely planarized surface, and thus the upper core layer cannot be precisely formed in a predetermined shape.

10 The thin film magnetic head shown in Fig. 26 also has the following problem. In the thin film magnetic head shown in Fig. 26, in order to suppress the occurrence of side fringing, the front side of the thin film magnetic head must be trimmed in such a shape as shown in Fig. 27. The side fringing is a phenomenon in which the track width is substantially increased by a leakage of a magnetic field from both sides. The occurrence of the side fringing must be prevented as much as possible as the recording density increases.

20 Therefore, as shown in Fig. 27, both side ends 11a of the upper core layer 11, both side ends 10a of the gap layer 10 and both side ends 6c of the protrusion 6a of the lower core layer 6 are trimmed to set the track width Tw to the greatest extent possible.

25 However, the required track width Tw is as small as about 0.3 μm or less to cause a difficulty in realizing this width dimension by trimming. Also, trimming has the problem of readhesion to cause a difficulty in improving the

precision of the track width Tw.

Unlike the thin film magnetic head shown in Fig. 26, in the thin film magnetic head shown in Fig. 28, a nonmagnetic layer is not formed on the gap layer 18. Therefore, the top 5 18a of the gap layer 18 and the top 14b of the back gap layer 14 can be planarized, and thus the upper core layer 19 can be formed on the planarized surface, thereby facilitating the precise formation of the upper core layer 19 in comparison to the thin film magnetic head shown in Fig. 26.

10 However, like in the thin film magnetic head shown in Fig. 26, in the thin film magnetic head shown in Fig. 28, both side ends of the upper core layer 19, both side ends of the gap layer 18 and both side ends of the protrusion 13a in the track width direction are trimmed to set the track width 15 Tw. Therefore, as described above with reference to Fig. 27, the track width Tw cannot be easily precisely defined due to the problem of readhesion during trimming.

In the thin film magnetic head shown in Fig. 28, the gap layer 18 comprises an inorganic insulating material such as 20 Al_2O_3 or the like, and the gap layer 18 must be avoided from being formed at a connection between the back gap layer 14 and the upper core layer 19. Therefore, as shown in Fig. 28, the gap layer 18 is absent from the connection between the back gap layer 14 and the upper core layer 19. In 25 manufacturing the structure shown in Fig. 28, a through hole for forming the back gap layer 14 must be formed in the gap layer 18 and the coil insulating layer 16 after the gap layer 18 is formed, and then the back gap layer 14 must be formed

in the through hole by plating, complicating the manufacturing process. Particularly, if the through hole does not completely extend from the top 18a of the gap layer 18 to the surface of the lower core layer 13, magnetic connection between the lower core layer 13 and the back gap layer 14 deteriorates to deteriorate the recording property. However, the coil insulating layer 16 is relatively thick, and thus it is difficult to form the through hole completely passing through the coil insulating layer 16.

10 As described above, the thin film magnetic heads shown in Figs. 25, 26 and 28 cannot be properly adapted for a higher recording density and higher frequency in future, and cannot be improved in the recording property.

15 SUMMARY OF THE INVENTION

Accordingly, the present invention has been achieved for solving the problems of conventional magnetic heads, and an object of the present invention is to provide a thin film magnetic head which is adaptable for a narrower track, and in which a track width can precisely formed to a predetermined dimension, a magnetic path can be shortened, and the recording property can be improved.

Another object of the present invention is to provide a method of manufacturing a thin film magnetic head capable of easily manufacturing the above-described thin film magnetic head by a small number of steps.

A thin film magnetic head of the present invention comprises a lower core layer extending from a surface facing

a recording medium in a height direction, a protruding layer extending on the lower core layer for a predetermined length from the surface facing the recording medium in the height direction, a back gap layer disposed on the lower core layer at a predetermined distance apart from the rear end of the protruding layer in the height direction, a coil layer disposed in a space surrounded by at least the lower core layer, the protruding layer and the back gap layer, and a coil insulating layer covering the coil layer, the top of the protruding layer, the top of the coil insulating layer and the top of the back gap layer being planarized to a continuous flat surface.

A Gd-determining layer is further formed on the flat surface at a predetermined distance apart from the surface facing the recording medium in the height direction.

Also, a lower magnetic pole layer and gap layer are formed on the flat surface in that order from below in each of a region between the Gd-determining layer and the surface facing the recording medium and a region behind the Gd-determining layer in the height direction, and an upper magnetic pole layer is formed over the gap layer and the Gd-determining layer.

The lower magnetic pole layer, the gap layer and the upper magnetic pole layer have a same planar shape, and a track width T_w is determined by the width dimension of the upper magnetic pole layer in the track width direction at the surface facing the recording medium.

The thin film magnetic head of the present invention is

characterized in that the coil layer is formed in the space surrounded by the lower core layer, the protruding layer and the back gap layer, the top of the protruding layer, the top of the coil insulating layer and the top of the back gap layer are planarized to a continuous flat surface, and the three layers including the lower magnetic pole layer, the gap layer and the upper magnetic pole layer are formed on the flat surface.

Since the lower magnetic pole layer, the gap layer and the upper magnetic pole layer can be formed on the flat surface, the three layers can be precisely formed in a predetermined shape, and the track width T_w can be easily set to a predetermined dimension by the width dimension of the upper magnetic pole layer at the surface facing the recording medium. It is thus possible to manufacture a thin film magnetic head appropriately adaptable to a higher recording density.

Since the lower magnetic pole layer, the gap layer and the upper magnetic pole layer can be formed on the flat surface, the magnetic path can be shortened. Therefore, even with a small number of coil turns, deterioration of the recording property can be prevented. Thus, the number of coil turns can be decreased to decrease the coil resistance, and the problem of projection due to thermal expansion can be properly suppressed.

Also, unlike the thin film magnetic head shown in Fig. 25, the thin film magnetic head of the present invention does not require an organic insulating layer, and thus the thermal

expansion coefficient can be decreased to appropriately suppress the problem of projection due to thermal expansion.

In the present invention, the Gd-determining layer is provided on the flat surface, for functionally separating
5 each the lower magnetic pole layer and upper magnetic pole layer into a magnetic pole and a yoke. Namely, at least a portion of each of the lower magnetic pole layer and upper magnetic pole layer, which is ahead of the Gd-determining layer, functions as the magnetic pole for concentrating a
10 magnetic flux to generate a recording magnetic field for the recording medium, and at least a portion behind the Gd-determining layer functions as the yoke for effectively flowing a magnetic flux in the closed magnetic path. In the present invention, the magnetic pole and the yoke are
15 integrally formed, but the magnetic pole and yoke can be appropriately separated by providing the Gd-determining layer.

In the present invention, the lower magnetic pole layer, the gap layer and the upper magnetic pole layer are preferably formed by plating. When the three layers are
20 formed by plating, a narrower tack can be realized without a conventional trimming step.

In the present invention, preferably, the upper core layer is formed on the upper magnetic pole layer into the same planar shape as the upper magnetic pole layer, and the
25 upper magnetic pole layer and lower magnetic pole layer have a higher saturation magnetic flux density than that of the upper core layer. In the present invention, the upper core layer can be formed directly on the upper magnetic pole layer.

Since the surface of the upper magnetic pole layer is substantially planarized, the surface of the upper core layer can also be formed on the planarized surface to permit the high-precision formation of the upper core layer in a predetermined shape, as compared with a conventional magnetic head. When each of the upper magnetic pole layer and lower magnetic pole layer is formed by using a magnetic material having a higher saturation magnetic flux density than that of the upper core layer, the magnetic flux efficiency can be improved to improve the recording property.

In the present invention, the upper core layer is preferably formed to a larger thickness than that of the upper magnetic pole layer.

In the present invention, the upper magnetic pole layer and lower magnetic pole layer preferably have a higher saturation magnetic flux density than those of the lower core layer, the protruding layer and the back gap layer.

In the present invention, the upper magnetic pole layer preferably has a planar shape comprising a front end portion which has a width dimension corresponding to the track width at the surface facing the recording medium and which extends while maintaining the width dimension or widens so that the width dimension increases in the height direction, and a rear end portion which widens from the base end of the front end portion in the track width direction so that the width dimension further increases in the height direction. The upper magnetic pole layer having this planar shape can concentrate a magnetic flux in the front end portion serving

as the magnetic pole, and increase the magnetic flux efficiency in the rear end portion serving as the yoke.

In the present invention, the boundary between the bottom and the front end surface of the Gd-determining layer, which is positioned near the surface facing the recording medium, is positioned on the protruding layer, and the Gd-determining layer is formed from the protruding layer to the coil insulating layer.

The length dimension in the height direction from the boundary between the top and the rear end surface of the protruding layer in the height direction to the boundary between the bottom and the rear end surface of the Gd-determining layer in the height direction is preferably larger than the maximum thickness of the Gd-determining layer.

This construction can suppress a leakage of a recording magnetic field from the vicinity of the rear end surface of the Gd-determining layer in the height direction without passing through a regular route.

Also, the boundary between the bottom and the rear end surface of the Gd-determining layer is preferably positioned on the back gap layer or on the boundary between the top and the front end surface of the back gap layer, which is positioned near the surface facing the recording medium, and the Gd-determining layer is preferably disposed between the top of the coil insulating layer and the bottom of the upper magnetic pole layer. Consequently, it is possible to effectively suppress a leakage from the vicinity of the rear end surface of the Gd-determining layer in the height

(direction, and increase the thickness of the coil layer for decreasing the coil resistance.

In the present invention, a first plated underlying layer is preferably provided on at least a portion of the flat surface between the rear end surface of the Gd-determining layer and the front end surface of the back gap layer, which is positioned near the surface facing the recording medium, and the lower magnetic pole layer is preferably formed on the first plated underlying layer by plating. In this case, the first plated underlying layer can be formed by using a nonmagnetic metal material. In the present invention, a second plated underlying layer is preferably formed on the protruding layer separately from the first plated underlying layer so that at least the Gd-determining layer is positioned between the first and second plated underlying layers. The second plated underlying layer preferably comprises a magnetic material, and the lower magnetic pole layer is preferably formed on the second plated underlying layer by plating. In the present invention, the second plated underlying layer is also provided on the protruding layer, and the front end of the second plated underlying layer is exposed at the surface facing the recording medium. Therefore, the second plated underlying layer must comprise a magnetic material because if the second plated underlying layer comprises a nonmagnetic metal material, the second plated underlying layer functions as a pseudo-gap.

In the present invention, a third plated underlying

layer is partially formed on the Gd-determining layer, and the upper magnetic pole layer is preferably formed on the third plated underlying layer by plating. In this case, the upper magnetic pole layer can easily be formed in a

5 predetermined shape on the Gd-determining layer.

In the present invention, the coil layer may be formed on a plane parallel to the surface of the lower core layer into a shape in which it is wound around the back gap layer as a center, or the coil layer may comprise a plurality of
10 first coil segments formed in parallel to each other in the space surrounded by the lower core layer, the protruding layer and the back gap layer, and a plurality of second coil segments formed in parallel to each other on the upper magnetic pole layer with an insulating layer provided
15 therebetween, the first coil segments being non-parallel to the second coil segments.

Furthermore, an end of each first coil segment and an end of each second coil segments face each other in the thickness direction of the upper magnetic pole layer and are
20 connected to each other through a connecting part in the thickness direction to form a toroidal coil structure.

A method of manufacturing a thin film magnetic head of the present invention comprises the following steps:

(a) a step of forming a lower core layer to extend it
25 from a surface facing a recording medium in the height direction;

(b) a step of forming a coil insulating underlying layer on the lower coil layer, and forming a coil layer on the coil

insulating underlying layer within a predetermined region;

(c) a step of forming a protruding layer on the lower core layer before or after the step (b) so that the protruding layer extends from the surface facing the recording medium in a height direction and is out of contact with the front end surface of the coil layer near the surface facing the recording medium, and forming a back gap layer on the lower core layer at a distance apart from the rear end surface of the protruding layer in the height direction so that the back gap layer is out of contact with the coil layer;

(d) a step of covering the coil layer with a coil insulating layer so that the top of the protruding layer, the top of the insulating layer and the top of the back gap layer are formed in a continuous flat surface;

(e) a step of forming a Gd-determining layer on the flat surface at a predetermined distance apart from the surface facing the recording medium; and

(f) a step of forming a lower magnetic pole layer and a gap layer on the flat surface in each of a region ahead of the Gd-determining layer near the surface facing the recording medium and a rear region behind the Gd-determining layer in the height direction, and further forming an upper magnetic pole layer over the gap layer and the Gd-determining layer.

In the method of manufacturing the thin film magnetic head, the coil layer is buried between the protruding layer and the back gap layer formed on the lower core layer, and a

(three-layer structure comprising the lower magnetic pole layer, the gap layer and the upper magnetic pole layer can easily be formed on the planarized surface including the top of the producing layer, the top of the insulating layer and
5 the top of the back gap layer. Since the three-layer structure can be formed on the planarized surface, the three-layer structure can be precisely formed in a predetermined shape to manufacture a thin film magnetic head appropriately adaptable for a higher recording density.

10 In the present invention, the lower magnetic pole layer, the gap layer and the upper magnetic pole layer are preferably continuously formed by plating in the step (f). Thus, the three layers including the lower magnetic pole layer, the gap layer and the upper magnetic pole layer can
15 easily be formed in a predetermined shape, and particularly, the track width which is determined by the width dimension of the upper magnetic pole layer at the surface facing the recording medium can be precisely regulated.

In the present invention, the upper core layer is
20 preferably continuously formed on the upper magnetic pole layer by plating after the step (f), and each of the upper magnetic pole layer and lower magnetic pole layer is preferably formed by using a material having a higher saturation magnetic flux density than that of the upper core
25 layer in the step (f).

In the present invention, in the step (f), each of the upper magnetic pole layer and lower magnetic pole layer is preferably formed by using a material having a higher

saturation magnetic flux density than those of the upper core layer, the protruding layer and the back gap layer.

In the present invention, the lower magnetic pole layer, the gap layer and the upper magnetic pole layer are provided on the planarized surface, and the upper core layer is further provided on these three layers. Therefore, the material of each of the layers can be selected from a wide range, and a material having a higher saturation magnetic flux density can be selected for the lower magnetic pole layer and the upper magnetic pole layer each of which functions as a magnetic pole at the surface facing the recording medium. Furthermore, the lower magnetic pole layer and the upper magnetic pole layer are also provided in the region behind the Gd-determining layer in the height direction so as to function as the yoke in this region. However, the yoke comprises a layer having a high saturation magnetic flux density, and thus a thin film magnetic head having excellent magnetic flux efficiency can be manufactured.

In the present invention, in the step (f), the upper magnetic pole layer is preferably formed in a planar shape comprising a front end portion which has a width dimension corresponding to the track width at the surface facing the recording medium and which extends while maintaining the width dimension or widens so that the track width increases in the height direction, and a rear end portion which widens from the base end of the front end portion in the track width direction so that the width dimension further increases in the height direction. The lower magnetic pole layer, the gap

layer and the upper core layer are preferably formed in the same planar shape as that of the upper magnetic pole layer.

In the present invention, in the step (e), the Gd-determining layer is preferably formed from the protruding
5 layer to the coil insulating layer so that the boundary between the bottom and the front end surface of the Gd-determining layer, which is positioned near the surface facing the recording medium, is positioned on the protruding layer, and the length dimension in the height direction from
10 the boundary between the top and the rear end surface of the protruding layer in the height direction to the boundary between the bottom and the rear end surface of the Gd-determining layer in the height direction is larger than the maximum thickness of the Gd-determining layer.

15 Also, in the present invention, the Gd-determining layer is preferably formed from the protruding layer to the coil insulating layer or from the protruding layer to the coil insulating layer and the back gap layer so that the boundary between the bottom and the rear end surface of the Gd-determining layer is positioned on the back gap layer or on
20 the boundary between the top and the front end surface of the back gap layer, which is positioned near the surface facing the recording medium, and the Gd-determining layer is disposed between the top of the coil insulating layer and the
25 bottom of the upper magnetic pole layer.

In the present invention, between the steps (d) and (e), a first plated underlying layer is preferably formed on at least a portion of the flat surface between the rear end

(surface of the Gd-determining layer in the height direction and the front end surface of the back gap layer, which is positioned near the surface facing the recording medium in the height direction, and the lower magnetic pole layer is preferably formed on the first plated underlying layer by plating. In this case, the first plated underlying layer may be made of a nonmagnetic metal material.

In the present invention, a second plated underlying layer is preferably formed on the protruding layer separately from the first plated underlying layer so that at least the Gd-determining layer is disposed between the first and second plated underlying layers. The second plated underlying layer preferably comprises a magnetic material, and the lower magnetic pole layer is preferably formed on the second plated underlying layer.

In the present invention, a third plated underlying layer is preferably partially formed on the Gd-determining layer, and the upper magnetic pole layer is preferably formed on the third plated underlying layer by plating.

Furthermore, in the present invention, the coil layer may be formed on a plane parallel to the surface of the lower core layer into a shape in which it is wound around the back gap layer as a center, or the coil layer may comprise a plurality of first coil segments formed in parallel to each other in the space surrounded by the lower core layer, the protruding layer and the back gap layer, and a plurality of second coil segments formed in parallel to each other on the upper magnetic pole layer with an insulating layer provided

therebetween, the first coil segments being non-parallel to the second coil segments.

Furthermore, an end of each first coil segments and an end of each second coil segments face each other in the thickness direction of the upper magnetic pole layer and are connected to each other through a connecting part in the thickness direction to form a toroidal coil structure.

Embodiments of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Fig. 1 is a longitudinal sectional view showing a structure of a thin film magnetic head according to a first embodiment of the present invention;

Fig. 2 is a partial perspective view of the thin film magnetic head shown in Fig. 1;

Fig. 3 is an enlarged longitudinal partial sectional view of the thin film magnetic head shown in Fig. 1;

Fig. 4 is an enlarged longitudinal partial sectional view of the thin film magnetic head shown in Fig. 1;

Fig. 5 is a longitudinal sectional view showing a structure of a thin film magnetic head according to a second embodiment of the present invention;

Fig. 6 is a partial front view of the thin film magnetic head shown in Fig. 5;

Fig. 7 is a partial plan view showing the coil shape of a coil layer of the thin film magnetic head shown in Fig. 5;

Fig. 8 is a drawing showing a step of a method of manufacturing the thin film magnetic head shown in Fig. 1;

Fig. 9 is a drawing showing a step after the step shown

in Fig. 8;

Fig. 10 is a drawing showing a step after the step shown in Fig. 9;

Fig. 11 is a drawing showing a step after the step shown
5 in Fig. 10;

Fig. 12 is a drawing showing a step after the step shown in Fig. 11;

Fig. 13 is a drawing showing a step after the step shown in Fig. 12;

10 Fig. 14 is a drawing showing a step after the step shown in Fig. 13;

Fig. 15 is a longitudinal sectional view showing a first example of a structure of a thin film magnetic head according to a third embodiment of the present invention;

15 Fig. 16 is a partial perspective view of the thin film magnetic head shown in Fig. 15;

Fig. 17 is a partial plan view of the thin film magnetic head shown in Fig. 15;

Fig. 18 is an enlarged longitudinal partial sectional
20 view of the thin film magnetic head shown in Fig. 15;

Fig. 19 is a longitudinal sectional view showing a second example of the structure of the thin film magnetic head according to the third embodiment of the present invention;

25 Fig. 20 is a partial perspective view of the thin film magnetic head shown in Fig. 19;

Fig. 21 is a partial plan view of the thin film magnetic head shown in Fig. 19;

Fig. 22 is an enlarged longitudinal partial sectional view of the thin film magnetic head shown in Fig. 19;

Fig. 23 is a longitudinal sectional view showing a first example of a structure of a thin film magnetic head according to a fourth embodiment of the present invention;

Fig. 24 is a longitudinal sectional view showing a second example of the structure of the thin film magnetic head according to the fourth embodiment of the present invention;

Fig. 25 is a longitudinal partial sectional view showing the structure of an example of conventional thin film magnetic heads;

Fig. 26 is a longitudinal partial sectional view of another example of conventional thin film magnetic heads;

Fig. 27 is a partial front view of the thin film magnetic head shown in Fig. 26; and

Fig. 28 is a longitudinal partial sectional view of a further example of conventional thin film magnetic heads.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 is a longitudinal partial sectional view showing a structure of a thin film magnetic head according to a first embodiment of the present invention, Fig. 2 is an enlarged partial perspective view showing a portion of the structure of the thin film magnetic head shown in Fig. 1, and Figs. 3 and 4 are longitudinal partial sectional views each showing the pattern of a plated underlying layer of the thin film magnetic head shown in Fig. 1.

Hereinafter, the X direction is referred to as the "track width direction", and the Y direction is referred to as the "height direction". The Z direction coincides with the movement direction of a recording medium (magnetic disk).
5 Also, the front end surface (the leftmost surface in each drawing) of the thin film magnetic head is referred to as the "surface facing a recording medium".

In the drawings, reference numeral 20 denotes a substrate comprising alumina-titanium carbide ($\text{Al}_2\text{O}_3\text{-TiC}$), an
10 Al_2O_3 layer 21 being formed on the substrate 20.

Also, a lower shield layer 22 composed of a NiFe alloy, sendust, or the like is formed on the Al_2O_3 layer 21, and a lower gap layer 23 composed of Al_2O_3 or the like is formed on the lower shield layer 22.

15 Furthermore, a magnetoresistive element 24, for example, a GMR element such as a spin-valve thin film element, is formed on the lower gap layer 23 near the surface facing the recording medium, an electrode layer 25 is formed on both sides of the magnetoresistive element 24 in the track width
20 direction (the X direction) to extend in the height direction (the Y direction).

Furthermore, an upper gap layer 26 composed of Al_2O_3 or the like is formed over the magnetoresistive element 24 and the electrode layer 25, and an upper shield layer 27 composed
25 of a NiFe alloy or the like is formed over the upper gap layer 26.

The portion ranging from the lower shield layer 22 to the upper shield layer 27 is referred to as a "reproducing

head" (MR head).

As shown in Fig. 1, a separating layer 28 comprised of Al_2O_3 is formed on the upper shield layer 27. The upper shield layer 27 and the separating layer 28 are not necessarily provided, and a lower core layer 29 may be provided on the upper gap layer 26. In this case, the lower core layer 29 also functions as an upper shield layer.

The lower core layer 29 is formed on the separating layer 28, and comprises a magnetic material such as a NiFe alloy or the like. The lower core layer 29 is formed with a predetermined length dimension from the surface facing the recording medium in the height direction (the Y direction). A lift layer 30 having a surface at the same height as the surface of the lower core layer 29 is formed at a predetermined distance apart from the base end surface 29a of the lower core layer 29. The space between the lower core layer 29 and the lift layer 30 is filled with a nonmagnetic material layer 31 composed of Al_2O_3 or the like. The surfaces of the lower core layer 29, the lift layer 30 and the nonmagnetic material layer 31 are planarized to a continuous flat surface.

Furthermore, a protruding layer 32 is formed on the lower core layer 29 to extend for a predetermined length dimension L_1 (refer to Fig. 2) from the surface facing the recording medium in the height direction (the Y direction). Furthermore, a back gap layer 33 is formed on the lower core layer 29 at a predetermined distance apart from the rear end surface 32a of the protruding layer 32 in the height

direction (the Y direction).

Each of the protruding layer 32 and the back gap layer 33 comprises a magnetic material which may be the same as or different from the material for the lower core layer 29.

- 5 Each of the protruding layer 32 and the back gap layer 33 may comprise a single-layer or multi-layer structure. The protruding layer 32 and the back gap layer 33 are magnetically connected to the lower core layer 29.

As shown in Fig. 1, a coil insulating underlying layer 10 34 comprising an insulating material such as Al_2O_3 , SiO_2 , or the like is formed over the lower core layer 29 and the lift layer 30, and a coil layer 35 is formed on the coil insulating underlying layer 34 so as to be wound around the back gap layer 33 as a center.

- 15 As shown in Fig. 1, the conductors of the coil layer 35 formed between the back gap layer 33 and the surface facing the recording medium are formed in the space surrounded by the lower core layer 29, the protruding layer 32 and the back gap layer 33.

- 20 The coil layer 35 is covered with a coil insulating layer composed of Al_2O_3 or the like. As shown in Fig. 1, a bottom-raising layer 37 is formed on each of the coil center 35a and the coil end 35b of the coil layer 35. The bottom-raising layer 37 comprises, for example, the same magnetic
25 material as the protruding layer 32 and the back gap layer 33.

As shown in Fig. 1, the top of the protruding layer 32, the top of the coil insulating layer 36 and the top of the bottom-raising layer 37 are planarized to a continuous flat

surface along the reference plane A shown in Fig. 1.

As shown in Fig. 1, a Gd-determining layer 38 is formed on the flat surface at a minimum distance L2 apart from the surface facing the recording medium in the height direction
5 (the Y direction).

In the embodiment shown in Fig. 1, the front end surface 38a of the Gd-determining layer 38 is positioned on the protruding layer 32, and the rear end surface 38b of the Gd-determining layer 38 is positioned on the coil insulating
10 layer 36.

As shown in Fig. 1, a lower magnetic pole layer 39 and a gap layer 40 are formed, in order from below, on the protruding layer 32 in a region between the surface facing the recording medium and the front end surface 38a of the Gd-determining layer 38, and on the coil insulating layer 36 and the back gap layer 33 in a region behind the rear end surface 38b of the Gd-determining layer 38 in the height direction.
15 In this embodiment, the lower magnetic pole layer 39 and the gap layer 40 are formed by plating.

As shown in Fig. 1, an upper magnetic pole layer 41 is formed over the gap layer 40 and the Gd-determining layer 38 by plating, and an upper core layer 42 is further formed on the upper magnetic pole layer 41 by plating.
20

In Fig. 1, an extension portion 43 is formed on the bottom-raising layer 37 exposed from the reference plane A.
25

The characteristic portions of the thin film magnetic head shown in Fig. 1 will be described below.

In Fig. 1, the protruding layer 32 is formed on the

lower core layer 29 near the surface facing the recording medium, and the back gap layer 33 is formed on a rear portion of the lower core layer 29 in the height direction. Also, the coil layer 35 is buried in the space surrounded by the lower core layer 29, the protruding layer 32, and the back gap layer 33. The top of the protruding layer 32, the top of the coil insulating layer 36 and the top of the back gap layer 33 are planarized to a continuous flat surface along the reference plane A. Furthermore, the four layers including the lower magnetic pole layer 39, the gap layer 40, the upper magnetic pole layer 41, and the upper core layer 42 are formed on the flat surface by plating.

Since the four layers can be formed on the flat surface, the four layers can be precisely formed in a predetermined shape. Particularly, the width of the upper magnetic pole layer 41 in the track width direction (the X direction) at the surface facing the recording medium is defined as the track width T_w , and thus the track width T_w can be precisely defined to a predetermined dimension because the upper magnetic pole layer 41 can be formed on the flat surface. In this embodiment, the track width T_w can be defined in the range of $0.1\ \mu\text{m}$ to $0.3\ \mu\text{m}$.

Since the top of the protruding layer 32 and the top of the back gap layer 33 are connected to each other by the four linear layers to form a magnetic path, the magnetic path can be shortened in comparison to a conventional magnetic path formed by a swelling layer formed below the upper core layer 42.

Therefore, even when the turn number of the coil layer 35 of the thin film magnetic head is decreased, the recording property can be maintained constant. Since the turn number can be decreased for decreasing the coil resistance, heat generation of the thin film magnetic head can be suppressed during driving, thereby suppressing the problem in which the gap layer 40 projects from the surface facing the recording medium.

Since the magnetic path can be shortened, the rate of magnetic field reversal can be increased to form a thin film magnetic head exhibiting excellent high-frequency performance.

The thin film magnetic head shown in Fig. 1 need not use an organic insulating material such as resist of the like for forming the coil insulating layer 36 to cover the coil layer 35, and an inorganic insulating material can be used. Therefore, the thermal expansion coefficient of the thin film magnetic head can be decreased.

In the thin film magnetic head shown in Fig. 1, the Gd-determining layer 38 is formed on the flat surface to extend from the protruding layer 32 to the coil insulating layer 36, so that the lower magnetic pole layer 39, the gap layer 40 and the upper magnetic pole layer 41 function as magnetic pole layers in the region between the surface facing the magnetic medium and at least the front end surface 38a of the Gd-determining layer 38, and function as yoke layers in the region behind the Gd-determining layer 38 in the height direction.

Although the lower magnetic pole layer 39, the gap layer

40 and the upper magnetic pole layer 41 are formed to extend from the protruding layer 32 to the back gap layer 33, each of the lower magnetic pole layer 39, the gap layer 40 and the upper magnetic pole layer 41 is divided by the Gd-determining layer 38 so as to function as different layers in the regions ahead of and behind the Gd-determining layers 38, thereby improving the recording property of the thin film magnetic head.

In the embodiment shown in Fig. 1, all of the four layers including the lower magnetic pole layer 39, the gap layer 40, the upper magnetic pole layer 41 and the upper core layer 42 are formed by plating, and thus the four layers can be formed by plating using a same frame to facilitate the formation. Also, since the four layers are formed by plating, the track width T_w determined by the width dimension of the upper magnetic pole layer 41 at the surface facing the recording medium can be precisely defined to a predetermined dimension, thereby eliminating the need for trimming for decreasing the track width T_w in a conventional magnetic head.

Since the four layers are formed by plating using the same frame, the four layers can be formed in the same planar shape.

Fig. 2 is a perspective view showing an example of the structure of the four layers. In Fig. 2, the lower magnetic pole layer 39, the gap layer 40, the upper magnetic pole layer 41 and the upper core layer 42 are formed in a planar shape comprising a front end portion B which has a constant width dimension at the surface facing in the track width

direction (the X direction) and extends while maintaining the width dimension in the height direction (the Y direction), and a rear end portion C which widens from the base end B1 of the front end portion B in the track width direction so that
5 the width gradually increases in the height direction (the Y direction). As described above, the track width Tw is defined by the width dimension of the upper magnetic pole layer 41 in the track width direction (the X direction) at the surface facing the recording medium.

10 The front end portion B may be formed in a shape in which the width dimension in the track width direction gradually increases from the surface facing the recording medium in the height direction. In this case, the width dimension in the track width direction further increases from
15 the base end B1 of the front end portion B in the height direction to form the rear end portion C.

With respect to the positional relation between the base end B1 of the front end portion B and the Gd-determining layer 38, Fig. 1 shows a case in which the base end B1 of the
20 front end portion B is behind the rear end surface 38b of the Gd-determining layer 38 in the height direction. However, the base end B1 may be positioned on the Gd-determining layer 38.

As shown in Fig 2, the gap depth (Gd) is determined by
25 the length of the top of the gap layer 40 from the surface facing the recording medium to the front end surface 38a of the Gd-determining layer 38 in the height direction (the Y direction). Therefore, as shown in Fig. 2, in order to

appropriately define the gap depth, the gap layer 40 is preferably divided into the portion between the front end surface 38a of the Gd-determining layer 38 and the surface facing the recording medium, and the portion behind the rear end surface 38b of the Gd-determining layer 38 in the height direction. The front end surface 38a of the Gd-determining layer 38 is preferably at a minimum distance L2 (refer to Fig. 1) of about 0.5 μm to 2.0 μm from the surface facing the recording medium in the height direction (the Y direction).
10 The gap depth (Gd) is preferably about 0.5 μm to 2.0 μm .

Although the Gd-determining layer 38 shown in Fig. 2 is rectangular, it may be formed in a shape having a semi-elliptic longitudinal section. Also, the Gd-determining layer 38 may comprise an organic material such as resist or the like, or an inorganic material. When the Gd-determining layer 38 comprises resist of the like, the surface of the Gd-determining layer 38 is rounded by heat.

Next, the materials of the lower magnetic pole layer 39 and upper magnetic pole layer 41 will be described below.
20 Each of the lower magnetic pole layer 39 and upper magnetic pole layer 41 preferably has a higher saturation magnetic flux density B_s than those of the upper core layer 42, the lower core layer 29, the protruding layer 32 and the back gap layer 33. Since each of the lower magnetic pole layer 39 and
25 upper magnetic pole layer 41, which face the gap layer 40, has a higher saturation magnetic flux density, a recording magnetic field can be concentrated near the gap to improve the recording density.

As shown in Fig. 1, the lower magnetic pole layer 39 and upper magnetic pole layer 41 extend from the rear end of the Gd-determining layer 38 in the height direction (the Y direction), and thus a region having a high saturation magnetic flux density B_s can be provided near the top of the coil layer 35. Therefore, the magnetic flux efficiency can be improved to form a thin film magnetic head having the excellent recording property.

A magnetic material such as a NiFe alloy, a CoFe alloy, a CoFeNi alloy, or the like can be used for the lower magnetic pole layer 39 and the upper magnetic pole layer 41, and a high saturation magnetic flux density B_s can be achieved by controlling the composition ratio of the magnetic material. In this embodiment, the high saturation magnetic flux density B_s is 1.8 T or more.

The lower magnetic pole layer 39 and the upper magnetic pole layer 41 may be formed in a single-layer structure or multi-layer structure.

The gap layer 40 shown in Fig. 1 comprises a nonmagnetic metal material, and is formed on the lower magnetic pole layer 39 by plating. As the nonmagnetic metal layer, at least one is preferably selected from NiP, NiPd, NiW, NiMo, NiRh, Au, Pt, Rh, Pd, Ru, and Cr. The gap layer 40 may be formed in a single-layer structure or multi-layer structure.

When the gap layer 40 comprises a NiP alloy, the gap layer 40 has ease of continuous plating, excellent heat resistance, and high adhesion to the lower magnetic pole layer 39 and the upper magnetic pole layer 41 in the

manufacturing process. Also, the hardness of the gap layer 40 can be set to the same as the lower magnetic pole layer 39 and the upper magnetic pole layer 41. Therefore, in processing the surface facing the recording medium, the lower magnetic pole layer 39, the gap layer 40 and the upper magnetic pole layer 41 can be processed by an equal amount by, for example, ion milling to improve processability.

The gap layer 40 preferably comprises a NiP alloy containing 8% by mass to 15% by mass of element P. The gap layer 40 is thus stably non-magnetic with an external factor, for example, generated heat or the like. The alloy composition of the gap layer comprising the NiP alloy can be measured by a X-ray analyzer, a wave dispersive linear analyzer, or the like in combination with SEM, TEM or the like.

Next, the upper core layer 42 will be described. The upper core layer 42 is also formed in the same planar shape as the lower magnetic pole layer 39, the gap layer 40 and the upper magnetic pole layer 41 by plating together with these layers. In the embodiment shown in Fig. 1, the upper core layer 42 can be formed on the substantially flat upper surface of the upper magnetic pole layer 41, and thus the upper core layer 42 can easily be formed in the predetermined shape with high precision, as compared with a conventional magnetic head.

The upper core layer 42 comprises the same magnetic material as that of the lower core layer 29, and the like, and may be formed in a single-layer or multi-layer structure.

(The upper core layer 42 is not necessarily formed, but it is preferably formed. The reason for this is that a layer having a high saturation magnetic flux density, such as the upper magnetic pole layer 41, the lower magnetic pole layer 5 39 or the like, has a low rate of plating growth and is thus not easily grown to a large thickness. On the other hand, the upper core layer 42 does not require such a high saturation magnetic flux density as required of the upper magnetic pole layer 41 and the lower magnetic pole layer 39, 10 and may have a low magnetic flux density, and the upper core layer 42 can thus be formed to a large thickness under soft plating conditions. Therefore, the recording property can be improved by providing the upper core layer 42.

The thickness of the upper core layer 42 is about 1 μm 15 to 3 μm . The thickness of the lower magnetic pole layer 39 is about 0.1 μm to 0.5 μm , the thickness of the gap layer 40 is about 0.05 μm to 0.15 μm , and the thickness of the upper magnetic pole layer 41 is about 0.1 μm to 1 μm .

Next, the protruding layer 32 will be described. In the 20 embodiment shown in Fig. 1, the protruding layer 32 is formed separately from the lower core layer 29 and is magnetically connected to the lower core layer 29. The protruding layer 32 may be formed integrally with the lower core layer 29. The protruding layer 32 may comprise the same material as or 25 a different material from the lower core layer 29. The protruding layer 32 may be formed in a single-layer or multi-layer laminated structure.

As shown in Fig. 2, the width dimension T1 of the

protruding layer 32 in the track width direction (the X direction shown in the drawing) at the surface facing the recording medium is greater than the width dimension of each of the lower magnetic pole layer 39, the gap layer 40, the upper magnetic pole layer 41 and the upper core layer 42 at the surface facing the recording medium. The width dimension T1 is about 5 μm to 30 μm . The length dimension L1 of the protruding layer 32 in the height direction is about 2 μm to 3 μm . The thickness dimension H1 of the protruding layer 32 is about 2.5 μm to 4 μm .

Next, a plated underlying layer for forming the lower magnetic pole layer 39 will be described below. In Fig. 3, the same reference numerals as those in Fig. 1 denote the same layers, and the description thereof is omitted.

As shown in Fig. 3, a second plated underlying layer 50 is formed on the protruding layer 32 to extend from the surface facing the recording medium in the height direction (the Y direction shown in the drawing). Furthermore, a first plated underlying layer 51 is formed on the coil insulating layer 36 to extend from a position at a predetermined distance from the rear end surface of the second plated underlying layer 50 in the height direction. The first plated underlying layer 51 is formed over the coil insulating layer 36 and the back gap layer 33 in the height direction (the Y direction).

As shown in Fig. 3, the Gd-determining layer 38 is formed to fill in the space 52 between the first plated underlying layer 51 and the second plated underlying layer 50

and to overlap with the upper surfaces of the first plated underlying layer 51 and the second plated underlying layer 50.

As shown in Fig. 3, the lower magnetic pole layer 39 is formed by plating on the second plated underlying layer 50 exposed between the front end surface 38a of the Gd-determining layer 38 and the surface facing the recording medium, and on the first plated underlying layer 51 exposed in the region extending from the rear end surface 38b of the Gd-determining layer 38 in the height direction. Furthermore, the gap layer 40 is formed on the lower magnetic pole layer 39.

In Fig. 3, the space 52 is provided between the first and second plated underlying layers 51 and 50, and the Gd-determining layer 38 fills in the space 52. If the first and second plated underlying layers 51 and 50 are provided as a continuous plated underlying layer by using a magnetic material, a magnetic flux partially leaks to the outside through the plated underlying layer in recording to cause a magnetic loss, resulting in deterioration in the recording property. Therefore, the first and second plated underlying layers 51 and 50 are provided with the space 52 therebetween.

The first plated underlying layer 51 may be made of a nonmagnetic metal material such as Cu or the like, not a magnetic material. On the other hand, the second plated underlying layer 50 must be made of a magnetic material. This is because the second plated underlying layer 50 is exposed at the surface facing the recording medium. If the second plated underlying layer 50 comprises a nonmagnetic

metal material, the second plated underlying layer 50 functions as a pseudo-gap to cause deterioration in the recording property. Therefore, the second plated underlying layer 50 must be made of a magnetic material, while the material of the first plated underlying layer 51 is not limited to the magnetic material because it is positioned apart from the surface facing the recording medium in the height direction.

The second plated underlying layer 50 is not necessarily formed. This is because the surface of the protruding layer 32 can be caused to function as the surface of a plated underlying layer. The first plated underlying layer 51 may be formed on at least a portion of the flat surface between the rear end surface 38b of the Gd-determining layer 38 and the front end surface 33a of the back gap layer 33. The portion of the first plated underlying layer 51, which is formed on the back gap layer 33, may be removed before the lower magnetic pole layer 39 is formed by plating, or the first plated underlying layer 51 may be formed so as not to be formed on the top of the back gap layer 33. Particularly, when the first plated underlying layer 51 comprises the nonmagnetic metal material, the portion of the first plated underlying layer 51, which is formed on the gap layer 33, causes a magnetic loss. In this case, the first plated underlying layer 51 is preferably formed so as not to be formed on the top of the back gap layer 33.

In Fig. 4, a third plated underlying layer 53 is partially formed on the Gd-determining layer 38. The reason

for partially providing the third plated underlying layer 53 on the Gd-determining layer 38 is to promote plating growth of the upper magnetic pole layer 41 on the third plated underlying layer 53 for preventing the formation of the
5 excessively thin upper magnetic pole layer 41 on the Gd-determining layer 38 by plating.

The reason for partially providing the third plated underlying layer 53 on the Gd-determining layer 38 is that if the third plated underlying layer 53 is provided in a wide
10 region including the front end surface 38a, the top and the rear end surface 38b of the Gd-determining layer 38, the lower magnetic pole layer 39 and the gap layer 40 are easily grown on the Gd-determining layer 38 by plating. As a result, unlike in the case shown in Fig. 4, the lower magnetic pole
15 layer 39 and the gap layer 40 cannot be formed in both the region ahead of the Gd-determining layer 38 and the region behind the Gd-determining layer 38 by plating, thereby impairing the effect of the Gd-determining layer 38. Thus, the third plated underlying layer 53 is partially provided on
20 the Gd-determining layer 38 apart from the lower magnetic pole layer 39 and the gap layer 40.

Fig. 5 is a longitudinal sectional view of a thin film magnetic head according to a second embodiment of the present invention, Fig. 6 is a partial front view of the thin film
25 magnetic head shown in Fig. 5, and Fig. 7 is a partial plan view showing the coil shape of a coil layer of the thin film magnetic head shown in Fig. 5. In the partial front view of Fig. 6, a protruding layer 32 and the like are omitted.

In Fig. 5, the same reference numerals as those in Fig. 1 denote the same layers as in Fig. 1. The embodiment shown in Fig. 5 is different in a method of winding a coil layer from the embodiment shown in Fig. 1.

5 In the thin film magnetic head shown in Fig. 5, a plurality of first coil segments 55 is formed in parallel to each other in a space surrounded by the lower core layer 29, the protruding layer 32 and the back gap layer 33.

The first coil segments 55 are arranged in parallel to, 10 for example, the track width direction (the X direction), as shown in the plan top view of Fig. 7.

As shown in Fig. 5, an insulating layer 58 comprising an insulating material, for example, Al_2O_3 or the like is formed over the lower magnetic pole layer 39, the gap layer 40, the 15 upper magnetic pole layer 41 and the upper core layer 42, and a plurality of second coil segments 56 is formed in parallel to each other on the insulating layer 58.

The second coil segments 56 are arranged, for example, in a direction inclined from the track width direction (the X 20 direction), as shown in the plan top view of Fig. 7.

In this way, the first coil segments 55 are non-parallel to the second coil segments 56, and as shown in Figs. 6 and 7, an end 55a of each first coil segment 55 and an end 56a of each second coil segment 56 face each other in the thickness 25 direction (the Z direction) of the four layers 62, and are connected to each other through a connecting portion 61. The connecting portion 61 shown by dotted lines on the right side of Fig. 6 connects an end 55a of the first coil segment 55

(next (in the Y direction) to the first coil segment 55 shown in the drawing to an end 56b of the second coil segment 56 shown in the drawing.

In this way, an end of each of the first coil segments 55 and an end of each of the second coil segments 56 face each other in the thickness direction of the four layers 62, and are connected to each other through the connecting portion 61 to form a toroidal coil layer 57. In Fig. 5, reference numeral 60 denotes a protective layer comprising Al_2O_3 or the like; in Fig. 6, reference numeral 63 denotes, for example, a resist layer; and in Figs. 5 and 7, reference numeral 59 denotes an extension layer. The extension layer 59 is formed in the same step as that for forming the second coil segments 56.

15 The reason why the so-called toroidal coil layer 57 shown in Figs. 5 to 7 can be formed is that the top of the protruding layer 32, the top of the coil insulating layer 36, and the top of the back gap layer 33 can be planarized, and the four layers 62 including the lower magnetic pole layer 39, 20 the gap layer 40, the upper magnetic pole layer 41 and the upper core layer 42 can be formed on the planarized surface. As a result, the top of the upper core layer 42 can be formed in a substantially flat surface, and the second coil segments 56 can be simply formed in a predetermined shape on the upper 25 core layer 42 with high precision.

The method of manufacturing the thin film magnetic head shown in Fig. 1 will be described below with reference to Figs. 8 to 14 which are drawings respectively showing

manufacturing steps. The method forming each of the layers ranging from the lower core layer 29 to the upper core layer 42 shown in Fig. 1 will be described. Each of the drawings is a longitudinal sectional view showing a step for
5 manufacturing the thin film magnetic head in the course of manufacture.

In the step shown in Fig. 8, the lower core layer 29 comprising a NiFe alloy or the like, and the raising layer 30 are formed by plating, and the space between the lower core
10 layer 29 and the raising layer 30 is filled with the nonmagnetic material layer 31 composed of Al_2O_3 or the like. Then, the surfaces of the lower core layer 29, the nonmagnetic material layer 31 and the raising layer 30 are polished to a flat surface.

15 In the next step shown in Fig. 9, the coil insulating underlying layer 34 composed of Al_2O_3 is formed over the surface of the lower core layer 29, the surface of the nonmagnetic material layer 31 and the surface of the raising layer 30 by sputtering or the like. Next, the coil layer 35
20 is spirally formed on the coil insulating underlying layer 34. The coil layer 35 is formed by plating a nonmagnetic conductive material such as Cu or the like.

In the next step shown in Fig. 10, the coil insulating underlying layer 34 is removed, by etching, from a region
25 between the surface facing the recording medium and the front end surface of the coil layer 35 near the surface facing the recording medium, and from a region near the base end portion of the lower core layer 29. Then, the protruding layer 32 is

(formed on the lower core layer 29 to extend for a predetermined length from the surface facing the recording medium in the height direction (the Y direction). In the same step, the back gap layer 33 is formed on the base end
5 portion of the lower core layer 29. The protruding layer 32 and the back gap layer 33 are magnetically connected to the lower core layer 29 without the coil insulating underlying layer 34 provided therebetween.

In the step shown in Fig. 10, the bottom-raising layer
10 37 is preferably formed on the coil center 35a and the coil end 35b of the coil layer 35 at the same time as the protruding layer 32 and the back gap layer 33 are formed.

The protruding layer 32, the back gap layer 33 and the bottom-raising layer 37 can be formed by a method in which a
15 pattern for these layers is formed in a resist layer by exposure, and then filled with a magnetic material layer by sputtering or the like. Then, the resist layer is removed.

As shown in Fig. 10, the top of the protruding layer 32, the top of the back gap layer 33 and the top of the bottom-raising layer 37 are formed at substantially the same height.
20 The step shown in Fig. 10 may be performed after the step shown in Fig. 8, and then the step shown in Fig. 9 may be performed. In this case, the bottom-raising layer 37 is formed in another step after the coil layer 35 is formed.

25 In the step shown in Fig. 11, the top of the coil layer 35, the top of the protruding layer 32, the top of the back gap layer 33 and the top of the bottom-raising layer 37 are covered with the coil insulating layer 36 composed of Al_2O_3

or the like. The coil insulating layer 36 is formed by sputtering.

Then, the coil insulating layer 36 is cut to line D-D in Fig. 11 by a CMP technique or the like in the direction 5 parallel to the X-Y plane. Fig. 12 shows a state after the completion of cutting.

In Fig. 12, the top of the protruding layer 32, the top of the coil insulating layer 36, the top of the back gap layer 33 and the top of the bottom-raising layer 37 are 10 planarized to a flat surface along the reference plane A. As shown in Fig. 12, the coil layer 35 is completely buried in the coil insulating layer 36.

In the next step shown in Fig. 13, the first and second plated underlying layers 51 and 50 are first formed on the 15 planarized surface by sputtering, and then the Gd-determining layer 38 is formed at a distance from the surface facing the recording medium in the height direction (the Y direction) so as to fill in the space 52 between the first and second plated underlying layers 51 and 50. The Gd-determining layer 20 38 may comprise an inorganic or organic insulating material. However, in this embodiment, the Gd-determining layer 38 comprises an organic insulating material such as resist or the like. After the Gd-determining layer 38 is formed at the predetermined position, the Gd-determining layer 38 is 25 thermally cured by heat treatment. In this step, the surface of the Gd-determining layer 38 comprising the organic insulating material is rounded. Next, the third plated underlying layer 53 is partially formed on the Gd-determining

layer 38 as shown in Fig. 4. Although there are several methods for partially forming the third plated underlying layer 53, a conceivable method for partially forming the third plated underlying layer 53 comprises forming a resist layer on portions of the Gd-determining layer 38, in which the third plated underlying layer 53 is not formed, forming the third plated underlying layer 53 on the Gd-determining layer 38 by sputtering, and then removing the resist layer. As described above with reference to Fig. 3, the first plated underlying layer 51 may comprise the nonmagnetic metal material. Also, the first plated underlying layer 51 may also be formed on the back gap layer 33. When the first plated underlying layer 51 is also formed on the back gap layer 33, the first plated underlying layer 51 may be then removed from the top of the back gap layer 33 by etching. Furthermore, the second plated underlying layer 50 is not necessarily formed. When the second plated underlying layer 50 is formed, it is made of a magnetic material. The third plated underlying layer 53 may comprise a magnetic material or nonmagnetic metal material.

In the next step shown in Fig. 14, a resist layer 65 is formed in a pattern 65a, for example, having the planar shape comprising the front end portion B and the rear end portion C shown in Fig. 2, and the lower magnetic pole layer 39, the gap layer 40, the upper magnetic pole layer 41 and the upper core layer 42 are formed in the pattern 65a by plating in that order from the bottom.

The lower magnetic pole layer 39, the gap layer 40, the

upper magnetic pole layer 41 and the upper core layer 42 have a planar shape comprising the elongated front end portion B extending from the surface facing the recording medium in the height direction (the Y direction), and the rear end portion C in which the width in the track width direction (the X direction) gradually increases from the base end B1 of the front end portion B in the height direction. In this case, the track width Tw is defined by the width dimension of the upper magnetic pole layer 41 in the track width direction (the X direction) at the surface facing the recording medium. Then, the resist layer 65 is removed.

The step shown in Fig. 14 is characterized in that the lower magnetic pole layer 39, the gap layer 40 and the upper magnetic pole layer 41 are formed by plating to extend from the surface facing the recording medium to the top of the back gap layer 33, and the upper core layer 42 is further continuously formed on the upper magnetic pole layer 41 by plating.

The lower magnetic pole layer 39, the gap layer 40 and the upper magnetic pole layer 41 basically constitute a magnetic pole, and are thus generally formed in a portion ranging from the surface facing the recording medium to the top of the Gd-determining layer 38.

However, in this step, the lower magnetic pole layer 39, the gap layer 40 and the upper magnetic pole layer 41 are formed to extend to the top of the back gap layer 33 so that the lower magnetic pole layer 39, the gap layer 40 and the upper magnetic pole layer 41 function as a "yoke" in the

region behind the Gd-determining layer 38 in the same manner as the upper core layer 42.

In this way, when the lower magnetic pole layer 39, the gap layer 40 and the upper magnetic pole layer 41 are formed to extend to the top of the back gap layer 33, the upper core layer 42 can be continuously formed on the upper magnetic pole layer 41 by plating.

As described above, when the lower magnetic pole layer 39, the gap layer 40 and the upper magnetic pole layer 41 are partially formed, a coil layer and insulating layer are generally formed behind the three layers. In this case, the upper surfaces of the upper magnetic pole layer 41 and the layer behind the upper magnetic pole layer 41 must be planarized by the CMP technique or the like, and thus the upper core layer 42 is formed after the planarizing step. However, in the step shown in Fig. 14, the lower magnetic pole layer 39, the gap layer 40 and the upper magnetic pole layer 41 are formed to extend to the top of the back gap layer 33 to eliminate the need for the planarizing step, thereby permitting the upper core layer 42 to be formed directly on the upper magnetic pole layer 41 by plating. Therefore, the upper core layer 42 can easily be formed on the substantially planarized surface of the upper magnetic pole layer 41 by a small number of steps, and thus the upper core layer can be formed in a predetermined shape with high precision.

In the step shown in Fig. 14, the upper magnetic pole layer 41 and the lower magnetic pole layer 39 can be formed

by using a material having a higher saturation magnetic flux density than those of the upper core layer 42, the lower core layer 29, the protruding layer 32 and the back gap layer 33. Consequently, a recording magnetic field can be concentrated near the gap to improve the recording density, and the magnetic flux efficiency can be improved by providing a layer having a high saturation magnetic flux density near the coil layer 35, thereby improving the recording property.

In the step shown in Fig. 14, the gap layer 40 is formed by plating, and thus the gap layer 40 is preferably made of a nonmagnetic metal material which can be plated. The gap layer 40 is preferably made of at least one material selected from NiP, NiPd, NiW, NiMo, Au, Pt, Rh, Pd, Ru, and Cr. By using any of these materials, the gap layer 40 can be appropriately formed to a predetermined thickness, and can be appropriately made non-magnetic.

When the gap layer 40 is made of a NiP alloy, the gap layer 40 has ease of plating, excellent heat resistance, and high adhesion to the upper magnetic pole layer 41. The gap layer 40 preferably comprises the NiP alloy containing 8% by mass to 15% by mass of P. Therefore, the gap layer 40 can be made stably non-magnetic for an external factor, for example, generated heat or the like. The alloy composition of the gap layer 40 comprising the NiP alloy or the like can be measured by a X-ray analyzer, a wave dispersive linear analyzer, or the like in combination with SEM, TEM or the like.

In forming the toroidal coil layer 57 shown in Figs. 5 to 7, the plurality of first coil segments 55 is formed in

the step shown in Fig. 9, and the connecting portions 61 shown in Figs. 6 and 7 are formed at the same time as the protruding layer 32 and the back gap layer 33 are formed in the step shown in Fig. 10. Furthermore, an insulating layer 58 and resist layer 63 are formed on the upper core layer 42 after the step shown in Fig. 14, and then the plurality of second coil segments 56 is formed on the insulating layer 58. In this step, an end of each of the second coil segments 56 may be magnetically connected to the corresponding connecting portion 61 to form the toroidal coil layer 57.

As described above, in the method of manufacturing the thin film magnetic head, the lower magnetic pole layer, the gap layer, the upper magnetic pole layer and the upper core layer can be easily formed in the predetermined shape with high precision by a small number of manufacturing steps.

Fig. 15 is a longitudinal partial sectional view showing a first example of a structure of a thin film magnetic head according to a third embodiment of the present invention, Fig. 16 is an enlarged partial perspective view showing a portion of the structure of the thin film magnetic head shown in Fig. 15, Fig. 17 is a partial plan view of the thin film magnetic head shown in Fig. 15, and Fig. 18 is a longitudinal partial sectional view of the thin film magnetic head shown in Fig. 15.

The thin film magnetic head shown in Fig. 15 comprises substantially the same structure as that of the thin film magnetic head shown in Figs. 1 to 4. Therefore, in the thin film magnetic head shown in Fig. 15, the same constituent

components as those of the thin film magnetic head shown in Figs. 1 to 4 are denoted by the same reference numerals, and the detailed description thereof is omitted.

In the thin film magnetic head shown in Fig. 15, the top of the protruding layer 32, the top of the coil insulating layer 36, the top of the back gap layer 33 and the top of the bottom-raising layer 37 are planarized to a continuous flat surface along the reference plane A shown in Fig. 15.

A Gd-determining layer 138 is formed on the flat surface to extend from a position at a minimum distance from the surface facing the recording medium in the height direction (the Y direction). The front end surface 138a of the Gd-determining layer 138 is positioned on the protruding layer 32, and the rear end surface 138b of the Gd-determining layer 138 is positioned on the coil insulating layer 36.

As shown in Fig. 17, the width dimension W1 of the Gd-determining layer 138 in the track width direction is preferably slightly larger than the maximum width dimension W2 of the upper core layer 42 in the track width direction. The reason for this will be described below.

Namely, since the Gd-determining layer 138 is formed, a stepped portion is formed on the upper magnetic pole layer 41 due to the thickness dimension T2 of the Gd-determining layer 138. The upper core layer 42 is formed on the upper magnetic pole layer 41 with a plated underlying layer provided therebetween, and the stepped portion is formed on the upper core layer 42. If the width dimension W1 of the Gd-determining layer 138 is smaller than the maximum width

dimension W2 of the upper core layer 42, two stepped portions extending in the height direction occurs on the plated underlying layer for forming the upper core layer 42 due to both side edges 138d and 138e of the Gd-determining layer 138, and a stepped portion extending in the track width direction occurs due to the rear end surface 138b of the Gd-determining layer 138. When the stepped portions are formed on the plated underlying layer, the plated underlying layer is easily damaged in the stepped portions, and thus the core layer 2 cannot be easily formed by plating due to the damage to the plated underlying layer.

However, when the width dimension W1 of the Gd-determining layer 138 is larger than the maximum width dimension W2 of the upper core layer 42, both side edges 138d and 138e of the Gd-determining layer 138 are positioned outside the plated underlying layer for forming the upper core layer 42, and thus no stepped portion occurs on the plated underlying layer due to both side edges 138d and 138e of the Gd-determining layer 138. Therefore, the number of the stepped portions produced on the plated underlying layer can be decreased to improve the quality of the upper core layer 42.

Assuming that the length dimension from the contact portion 138c of the Gd-determining layer 138 in contact with the rear end surface 32a of the protruding layer 32 to the rear end surface 138b of the Gd-determining layer 138 is L3, the length dimension L3 is larger than the thickness dimension T1 of the Gd-determining layer 138. If the length

dimension L3 is small than the thickness dimension T1, the produced magnetic flux easily flows from the upper magnetic pole layer 41 to the lower magnetic pole layer 39 near the rear end surface 138b of the Gd-determining layer 138 before
5 flowing from the upper magnetic pole layer 41 to the lower magnetic pole layer 39 at the surface facing the recording medium, thereby easily producing a leakage of the magnetic flux. This is because the magnetic flux has the property of easily flowing through a portion with low magnetic resistance.
10 Particularly, the magnetic flux easily flows from the corner 138P of the rear end surface 138b of the Gd-determining layer 138 to the corner 32Q of the rear end surface 32a of the protruding layer 32.

However, as shown in Fig. 18, in the thin film magnetic head shown in Fig. 15, the length dimension L3 is larger than
15 the thickness dimension T1, and thus the length dimension from the corner 138P of the Gd-determining layer 138 to the corner 32Q of the rear end surface 32a of the protruding layer 32 can be increased. Therefore, the magnetic flux is
20 difficult to flow from the corner 138P to the corner 32Q, and thus a magnetic field easily occurs at the surface facing the recording medium. Therefore, in the thin film magnetic head shown in Fig. 15, the recording efficiency can be increased.

Fig. 19 is a longitudinal partial sectional view showing
25 a second example of the structure of the thin film magnetic head according to the third embodiment of the present invention, Fig. 20 is an enlarged partial perspective view showing a part of the structure of the thin film magnetic

head shown in Fig. 19, Fig. 21 is a partial plan view of the thin film magnetic head shown in Fig. 19, and Fig. 22 is a longitudinal partial sectional view of the thin film magnetic head shown in Fig. 19.

5 The thin film magnetic head shown in Fig. 19 comprises substantially the same structure as that of the thin film magnetic head shown in Figs. 1 to 4. Therefore, in the thin film magnetic head shown in Fig. 19, the same constituent components as those of the thin film magnetic head shown in
10 Figs. 1 to 4 are denoted by the same reference numerals, and the detailed description thereof is omitted.

 In the thin film magnetic head shown in Fig. 19, the top of a coil layer 135 is formed as the reference plane A shown in Fig. 19, and the top of the protruding layer 32, the top
15 of the coil layer 135, the top of the coil insulating layer 36, the top of the back gap layer 33 and the top of the bottom-raising layer 37 are planarized to a continuous flat surface along the reference plane A.

 A Gd-determining layer 238 is formed on the flat surface
20 to extend from a position at a minimum distance from the surface facing the recording medium in the height direction (the Y direction). The front end surface 238a of the Gd-determining layer 238 is positioned on the protruding layer 32, and the rear end surface 238b of the Gd-determining layer
25 238 is positioned on the back gap layer 33. The rear end surface 238b of the Gd-determining layer 238 may be positioned on the boundary 33b between the top of the back gap layer 33 and the front end surface 33a of the back gap

layer 33 near the surface facing the recording medium.

In the thin film magnetic head shown in Fig. 19, the Gd-determining layer 238 is formed on the coil layer 135, and comprises an organic insulating material. Therefore, even when the top of the coil layer 135 is formed to a level equal to the reference plane A and to be in contact with the bottom of the Gd-determining layer 238, the coil layer 135 can be insulated. Therefore, the sectional area of the coil layer 135 can be increased to decrease the resistance. However, the present invention is not limited to this example, and like in the thin film magnetic head shown in Fig. 15, the coil layer 135 may be formed to a level lower than the reference plane A so that the coil insulating layer 36 is formed on the top of the coil layer 135.

Like in the thin film magnetic head shown in Fig. 15, in the thin film magnetic head shown in Fig. 19, the width dimension W3 of the Gd-determining layer 238 in the track width direction is preferably larger than the maximum width dimension W2 of the upper core layer 42 in the track width direction in order to improve the quality of the upper core layer 42, as shown in Fig. 21.

Assuming that the length dimension from the contact portion 238c of the Gd-determining layer 238 in contact with the rear end surface 32a of the protruding layer 32 to the rear end surface 238b of the Gd-determining layer 238 is L4, the length dimension L4 is larger than the thickness dimension T2 of the Gd-determining layer 238. Therefore, in the thin film magnetic head shown in Fig. 19, the length

dimension from the corner 238P of the Gd-determining layer 238 to the corner 32Q of the rear end surface 32a of the protruding layer 32 can be increased. Thus, the magnetic flux is difficult to flow from the corner 238P to the corner 32Q, and thus a magnetic field easily occurs at the surface facing the recording medium. Therefore, in the thin film magnetic head shown in Fig. 19, the recording efficiency can be increased.

Fig. 23 is a longitudinal partial sectional view showing a first example of a structure of a thin film magnetic head according to a fourth embodiment of the present invention. The thin film magnetic head shown in Fig. 23 comprises substantially the same structure as that of the thin film magnetic head shown in Figs. 5 to 7. Therefore, in the thin film magnetic head shown in Fig. 23, the same constituent components as those of the thin film magnetic head shown in Figs. 5 to 7 are denoted by the same reference numerals, and the detailed description thereof is omitted.

In the thin film magnetic head shown in Fig. 23, the top of the protruding layer 32, the top of the coil insulating layer 36, the top of the back gap layer 33 and the top of the bottom-raising layer 37 (not shown in the drawing), which is formed at a predetermined distance from the back gap layer 33 in the height direction, are planarized to a continuous flat surface along the reference plane A shown in Fig. 23. A Gd-determining layer 338 is formed on the flat surface to extend from a position at a minimum distance from the surface facing the recording medium in the height direction (the Y

direction). The front end surface 338a of the Gd-determining layer 338 is positioned on the protruding layer 32, and the rear end surface 338b of the Gd-determining layer 338 is positioned on the coil insulating layer 36.

5 Like in the thin film magnetic head shown in Fig. 15, in the thin film magnetic head shown in Fig. 23, the width dimension of the Gd-determining layer 338 in the track width direction is preferably larger than the maximum width dimension W2 of the upper core layer 42 in the track width
10 direction in order to improve the quality of the upper core layer 42.

 Assuming that the length dimension from the contact portion 338c of the Gd-determining layer 338 in contact with the rear end surface 32a of the protruding layer 32 to the
15 rear end surface 338b of the Gd-determining layer 338 is L5, the length dimension L5 is larger than the thickness dimension T3 of the Gd-determining layer 338. Therefore, in the thin film magnetic head shown in Fig. 23, the length dimension from the corner 338P of the Gd-determining layer
20 338 to the corner 32Q of the rear end surface 32a of the protruding layer 32 can be increased. Thus, the magnetic flux is difficult to flow from the corner 338P to the corner 32Q, and thus a magnetic field easily occurs at the surface facing the recording medium. Therefore, in the thin film
25 magnetic head shown in Fig. 23, the recording efficiency can be increased.

 Fig. 24 is a longitudinal partial sectional view showing a second example of the structure of the thin film magnetic

head according to the fourth embodiment of the present invention. The thin film magnetic head shown in Fig. 24 comprises substantially the same structure as that of the thin film magnetic head shown in Figs. 5 to 7. Therefore, in the thin film magnetic head shown in Fig. 24, the same constituent components as those of the thin film magnetic head shown in Figs. 5 to 7 are denoted by the same reference numerals, and the detailed description thereof is omitted.

In the thin film magnetic head shown in Fig. 24, the top of a coil layer 455 is formed as the reference plane A shown in Fig. 24, and the top of the protruding layer 32, the top of the coil layer 455, the top of the coil insulating layer 36, the top of the back gap layer 33 and the top of the bottom-raising layer 37 are planarized to a continuous flat surface along the reference plane A.

A Gd-determining layer 438 is formed on the flat surface to extend from a position at a minimum distance from the surface facing the recording medium in the height direction (the Y direction). Like in the thin film magnetic head shown in Fig. 19, the front end surface 438a of the Gd-determining layer 438 is positioned on the protruding layer 32, and the rear end surface 438b of the Gd-determining layer 438 is positioned on the back gap layer 33. The rear end surface 438b of the Gd-determining layer 438 may be positioned on the boundary 33b between the top of the back gap layer 33 and the front end surface 33a of the back gap layer 33 near the surface facing the recording medium.

In the thin film magnetic head shown in Fig. 24, the Gd-

determining layer 438 is formed on the coil layer 455, and comprises an organic insulating material. Therefore, even when the top of the coil layer 455 is formed to a level equal to the reference plane A and to be in contact with the bottom of the Gd-determining layer 438, the coil layer 455 can be insulated. Therefore, the sectional area of the coil layer 455 can be increased to decrease the resistance. However, the present invention is not limited to this example, and like in the thin film magnetic head shown in Fig. 23, the coil layer 455 may be formed to a level lower than the reference plane A, and the coil insulating layer 36 may be formed on the top of the coil layer 455.

Like in the thin film magnetic head shown in Fig. 15, in the thin film magnetic head shown in Fig. 24, the width dimension of the Gd-determining layer 438 in the track width direction is preferably larger than the maximum width dimension of the upper core layer 42 in the track width direction in order to improve the quality of the upper core layer 42.

Assuming that the length dimension from the contact portion 438c of the Gd-determining layer 438 in contact with the rear end surface 32a of the protruding layer 32 to the rear end surface 438b of the Gd-determining layer 438 is L6, the length dimension L6 is larger than the thickness dimension T4 of the Gd-determining layer 438. Therefore, in the thin film magnetic head shown in Fig. 24, the length dimension from the corner 438P of the Gd-determining layer 438 to the corner 32Q of the rear end surface 32a of the

protruding layer 32 can be increased. Thus, the magnetic flux is difficult to flow from the corner 438P to the corner 32Q, and thus a magnetic field easily occurs at the surface facing the recording medium. Therefore, in the thin film magnetic head shown in Fig. 24, the recording efficiency can be increased.

In manufacturing the thin film magnetic head shown in Fig. 15, in the step shown in Fig. 13, the Gd-determining layer 138 is formed so that its front end surface 138a is positioned on the protruding layer 32, and its rear end surface 138b is positioned on the coil insulating layer 36. The length dimension L3 is set to be larger than the thickness dimension T1.

In manufacturing the thin film magnetic head shown in Fig. 19, in the step shown in Fig. 13, the Gd-determining layer 238 is formed so that its front end surface 238a is positioned on the protruding layer 32, and its rear end surface 238b is positioned on the back gap layer 33. The length dimension L4 is set to be larger than the thickness dimension T2.

In manufacturing the thin film magnetic head shown in Fig. 23, like the thin film magnetic head shown in Fig. 15, in the step shown in Fig. 13, the Gd-determining layer 338 is formed so that its front end surface 338a is positioned on the protruding layer 32, and its rear end surface 338b is positioned on the coil insulating layer 36. The length dimension L5 is set to be larger than the thickness dimension T3.

The thin film magnetic head shown in Fig. 23 comprises a structure in which the toroidal coil layer 57 is formed. In manufacturing the thin film magnetic head shown in Fig. 23, the first coil segments 55 are formed in the step shown in Fig. 9, and then the connecting portions 61 shown in Figs. 6 and 7 are formed at the same time as the protruding layer 32 and the back gap layer 33 are formed in the step shown in Fig. 10. Furthermore, the insulating layer 58 and the resist layer 63 are formed on the upper core layer 42 after the step shown in Fig. 14, and then the plurality of second coil segments 56 is formed on the insulating layer 58 so that the ends of the second coil segments 56 are magnetically connected to the respective connecting portions 61 to form the toroidal coil layer 57. In forming the insulating layer 58 on the upper core layer 42 after the step shown in Fig. 14, the stepped portion due to the thickness dimension T3 of the Gd-determining layer 338 occurs on the top 58a of the insulating layer 58. In this case, the second coil segments 56 may be formed on the top 58a of the insulating layer 58 which is not planarized to leave the stepped portion. However, the second coil segments 56 are preferably formed after the top 58a of the insulating layer 58 is planarized to remove the stepped portion. The reason for this is that when the second coil segments 56 are formed on the top of the stepped portion, the second coil segments 56 are curved by the stepped portion, and thus cannot be formed with high precision. Therefore, as shown in Fig. 21, the top 58a of the insulating layer 58 is preferably planarized, and the

second coil segments 56 are then formed on the planarized top 58a because the second coil segments 56 can be formed with high precision.

Like in the thin film magnetic head shown in Fig. 16, in the thin film magnetic head shown in Fig. 24, in the step shown in Fig. 13, the Gd-determining layer 438 is formed so that its front end surface 438a is positioned on the protruding layer 32, and its rear end surface 438b is positioned on the back gap layer 33. The length dimension L6 is set to be larger than the thickness dimension T4.

Like the thin film magnetic head shown in Fig. 23, the thin film magnetic head shown in Fig. 24 comprises a structure in which the toroidal coil layer 57 is formed. In manufacturing the thin film magnetic head shown in Fig. 24, the first coil segments 55 are formed in the step shown in Fig. 9, and then the connecting portions 61 shown in Figs. 6 and 7 are formed at the same time as the protruding layer 32 and the back gap layer 33 are formed in the step shown in Fig. 10. Furthermore, the insulating layer 58 and the resist layer 63 are formed on the upper core layer 42 after the step shown in Fig. 14, and then the plurality of second coil segments 56 is formed on the insulating layer 58 so that the ends of the second coil segments 56 are magnetically connected to the respective connecting portions 61 to form the toroidal coil layer 57. In the process for manufacturing the thin film magnetic head shown in Fig. 24, after the insulating layer 58 is formed on the upper core layer 42 in the step shown in Fig. 14, the second coil segments 56 may be

formed on the top 58a of the insulating layer 58 which is not planarized. However, in order to form the second coil segments 56 with high precision, the second coil segments 56 are preferably formed after the top 58a of the insulating layer 58 is planarized to remove the stepped portion.

Each of the above-described thin film magnetic heads of the present invention is built in a magnetic head device mounted on, for example, a hard disk device or the like. The thin film magnetic head may be built-in either a floating-type magnetic head or contact-type magnetic head. The thin film magnetic head can also be used for a magnetic sensor and the like other than the hard disk device.

As described above, in the present invention, a coil layer is formed in a space surrounded by a lower core layer, a protruding layer and a back gap layer, the top of the protruding layer, the top of a coil insulating layer and the top of the back gap layer are planarized to a continuous flat surface, and the three layers including a lower magnetic pole layer, a gap layer and an upper magnetic pole layer are formed on the flat surface.

Since the lower magnetic pole layer, the gap layer and the upper magnetic pole layer are formed on the flat surface, the three layers can be precisely formed in a predetermined shape, and the track width T_w can be easily set to a predetermined dimension by the width dimension of the upper magnetic pole layer at the surface facing a recording medium. Therefore, a thin film magnetic head appropriately adaptable for a higher recording density can be manufactured.

Since the lower magnetic pole layer, the gap layer and the upper magnetic pole layer are formed on the flat surface, the magnetic path can be shortened. Therefore, even when the turn number of a coil is decreased, deterioration in the recording property can be prevented. It is thus possible to decrease the turn number to decrease the coil resistance, and appropriately suppress the problem of projection due to thermal expansion.

In the thin film magnetic head of the present invention, an organic insulating layer need not be provided, and thus the thermal expansion coefficient can be decreased to appropriately suppress the problem of projection due to thermal expansion.

Also, in the present invention, a Gd-determining layer is provided on the flat surface, and the lower magnetic pole layer and the upper magnetic pole layer are functionally divided into a magnetic pole and a yoke by the Gd-determining layer. Namely, in a region ahead of at least the Gd-determining layer, the lower magnetic pole layer and the upper magnetic pole layer function as the magnetic pole for concentrating a magnetic flux to generate a recording magnetic field for the recording medium, while in a region behind at least the Gd-determining layer, the lower magnetic pole layer and the upper magnetic pole layer function as the yoke for effectively flowing the magnetic flux in a closed magnetic path. In this way, the three layers can be functionally separated by providing the Gd-determining layer, and a thin film magnetic head having the excellent recording

property can be manufactured.

Furthermore, in the thin film magnetic head of the present invention, the length dimension from the contact portion of the Gd-determining layer in contact with the rear end surface of the protruding layer to the rear end surface of the Gd-determining layer is set to be larger than the thickness dimension of the Gd-determining layer. Therefore, the length dimension from the corner of the rear end surface of the Gd-determining layer to the corner of the rear end surface of the protruding layer can be increased. Thus, a magnetic flux is difficult to flow between both corners, and thus a magnetic field easily occurs at the surface facing the recording medium, thereby increasing the recording efficiency.

CLAIMS

1. A thin film magnetic head comprising:

a lower core layer extending from a surface facing a
5 recording medium in a height direction;

a protruding layer extending on the lower core layer for
a predetermined length from the surface facing the recording
medium in the height direction;

a back gap layer disposed on the lower core layer at a
10 predetermined distance apart from the rear end of the
protruding layer in the height direction;

a coil layer disposed in the space surrounded by at
least the lower core layer, the protruding layer and the back
gap layer;

15 a coil insulating layer covering the coil layer, the
tops of the protruding layer, the coil insulating layer and
the back gap layer being planarized to a continuous flat
surface;

a Gd-determining layer disposed on the flat surface at a
20 predetermined distance apart from the surface facing the
recording medium in the height direction.

a lower magnetic pole layer and gap layer disposed on
the flat surface in that order from below in each of a region
between the surface facing the recording medium and the Gd-
25 determining layer and a region behind the Gd-determining
layer in the height direction; and

an upper magnetic pole layer over the gap layer and the
Gd-determining layer;

wherein the lower magnetic pole layer, the gap layer and the upper magnetic pole layer have a same planar shape, and a track width T_w is determined by the width dimension of the upper magnetic pole layer in the track width direction at the surface facing the recording medium.

2. A thin film magnetic head according to claim 1, wherein the lower magnetic pole layer, the gap layer and the upper magnetic pole layer are formed by plating.

10

3. A thin film magnetic head according to claim 1, wherein the upper core layer is formed on the upper magnetic pole layer into the same planar shape as that of the upper magnetic pole layer, and the upper magnetic pole layer and lower magnetic pole layer have a higher saturation magnetic flux density than that of the upper core layer.

4. A thin film magnetic head according to claim 3, wherein the upper core layer is formed to a larger thickness than that of the upper magnetic pole layer.

5. A thin film magnetic head according to claim 1, wherein the upper magnetic pole layer and lower magnetic pole layer have a higher saturation magnetic flux density than those of the lower core, the protruding layer and the back gap layer.

6. A thin film magnetic head according to claim 1,

wherein the upper magnetic pole layer has a planar shape comprising a front end portion which has a width dimension corresponding to a track width at the surface facing the recording medium and which extends while maintaining the width dimension or widens so that the width dimension increases in the height direction, and a rear end portion which widens from the base end of the front end portion in the track width direction so that the width dimension further increases in the height direction.

10

7. A thin film magnetic head according to claim 1, wherein the boundary between the bottom and the front end surface of the Gd-determining layer, which is positioned near the surface facing the recording medium, is positioned on the protruding layer;

the Gd-determining layer is formed from the protruding layer to the coil insulating layer; and

the length dimension from the boundary between the top and the rear end surface of the protruding layer in the height direction to the boundary between the bottom and the rear end surface of the Gd-determining layer in the height direction is larger than the maximum thickness of the Gd-determining layer.

25 8. A thin film magnetic head according to claim 7, wherein the boundary between the bottom and the rear end surface of the Gd-determining layer is positioned on the back gap layer or on the boundary between the top and the front

(end surface of the back gap layer, which is positioned near the surface facing the recording medium, and the Gd-determining layer is disposed between the top of the coil insulating layer and the bottom of the upper magnetic pole layer.

9. A thin film magnetic head according to claim 1, further comprising a first plated underlying layer provided on at least a portion of the flat surface between the rear end surface of the Gd-determining layer and the front end surface of the back gap layer, which is positioned near the surface facing the recording medium, the lower magnetic pole layer being formed on the first plated underlying layer by plating.

15

10. A thin film magnetic head according to claim 9, wherein the first plated underlying layer comprises a nonmagnetic metal material.

20 11. A thin film magnetic head according to claim 9, further comprising a second plated underlying layer formed on the protruding layer apart from the first plated underlying layer, wherein at least the Gd-determining layer is disposed between the first and second plated underlying layers, the second plated underlying layer comprises a magnetic material, and the lower magnetic pole layer is formed on the second plated underlying layer by plating.

(12. A thin film magnetic head according to claim 1,
further comprising a third plated underlying layer partially
formed on the Gd-determining layer, the upper magnetic pole
layer being formed on the third plated underlying layer by
5 plating.

13. A thin film magnetic head according to claim 1,
wherein the coil layer is formed on a plane parallel to the
surface of the lower core layer so as to be wound around the
10 back gap layer as a center.

14. A thin film magnetic head according to claim 1,
wherein the coil layer comprises a plurality of first coil
segments formed in parallel to each other in the space
15 surrounded by the lower core layer, the protruding layer and
the back gap layer, and a plurality of second coil segments
formed in parallel to each other on the upper magnetic pole
layer with an insulating layer provided therebetween, the
first coil segments being non-parallel to the second coil
20 segments; and

an end of each first coil segment and an end of each
second coil segments face each other in the thickness
direction of the upper magnetic pole layer and are connected
to each other through a connecting portion to form a toroidal
25 coil structure.

15. A method of manufacturing a thin film magnetic head
comprising the steps of:

(a) forming a lower core layer to extend it from a surface facing a recording medium in a height direction;

(b) forming a coil insulating underlying layer on the lower coil layer, and forming a coil layer on the coil
5 insulating underlying layer within a predetermined region;

(c) forming a protruding layer on the lower core layer before or after the step (b) to extend the protruding layer from the surface facing the recording medium in a height direction so that the protruding layer is out of contact with
10 the front end surface of the coil layer near the surface facing the recording medium, and forming a back gap layer on the lower core layer at a distance apart from the rear end surface of the protruding layer in the height direction so that the back gap layer is out of contact with the coil
15 layer;

(d) covering the coil layer with a coil insulating layer so that the tops of the protruding layer, the insulating layer and the back gap layer are formed in a continuous flat surface;

20 (e) forming a Gd-determining layer on the flat surface at a predetermined distance apart from the surface facing the recording medium;

(f) forming a lower magnetic pole layer and a gap layer on the flat surface in a region between the Gd-determining layer and the surface facing the recording medium and a rear region behind the Gd-determining layer in the height direction, and further forming an upper magnetic pole layer over the gap layer and the Gd-determining layer.

25

(
16. A method of manufacturing a thin film magnetic head according to claim 15, wherein in the step (f), the lower magnetic pole layer, the gap layer and the upper magnetic pole layer are continuously formed by plating.
5

17. A method of manufacturing a thin film magnetic head according to claim 15, wherein each of the upper magnetic pole layer and the lower magnetic pole layer is formed by using a material having a higher saturation magnetic flux density than that of the upper core layer in the step (f), and the upper core layer is continuously formed on the upper magnetic pole layer by plating after the step (f).
10

18. A method of manufacturing a thin film magnetic head according to claim 15, wherein in the step (f), each of the upper magnetic pole layer and the lower magnetic pole layer is formed by using a material having a higher saturation magnetic flux density than those of the lower core layer, the protruding layer and the back gap layer.
15
20

19. A method of manufacturing a thin film magnetic head according to claim 15, wherein in the step (f), the upper magnetic pole layer is formed in a planar shape comprising a front end portion which has a width dimension corresponding to a track width at the surface facing the recording medium and which extends while maintaining the width dimension or widens so that the track width increases in the height
25

(direction, and a rear end portion which widens from the base end of the front end portion in the track width direction so that the width further increases in the height direction, and the lower magnetic pole layer, the gap layer and the upper core layer are formed in the same planar shape as that of the upper magnetic pole layer.

20. A method of manufacturing a thin film magnetic head according to claim 15, wherein in the step (e), the Gd-determining layer is formed from the protruding layer to the coil insulating layer so that the boundary between the bottom and the front end surface of the Gd-determining layer, which is positioned near the surface facing the recording medium, is positioned on the protruding layer, and the length dimension in the height direction from the boundary between the top and the rear end surface of the protruding layer in the height direction to the boundary between the bottom and the rear end surface of the Gd-determining layer in the height direction is larger than the maximum thickness of the Gd-determining layer.

21. A method of manufacturing a thin film magnetic head according to claim 20, wherein the Gd-determining layer is formed from the protruding layer to the coil insulating layer or from the protruding layer to the coil insulating layer and the back gap layer so that the boundary between the bottom and the rear end surface of the Gd-determining layer is positioned on the back gap layer or on the boundary between

(the top and the front end surface of the back gap layer,
which is positioned near the surface facing the recording
medium, and the Gd-determining layer is interposed between
the top of the coil insulating layer and the bottom of the
5 upper magnetic pole layer.

22. A method of manufacturing a thin film magnetic head
according to claim 15, further comprising forming a first
plated underlying layer on at least a portion of the flat
10 surface between the rear end surface of the Gd-determining
layer in the height direction and the front end surface of
the back gap layer, which is positioned near the surface
facing the recording medium, between the steps (d) and (e),
and forming the lower magnetic pole layer on the first plated
15 underlying layer by plating.

23. A method of manufacturing a thin film magnetic head
according to claim 22, wherein the first plated underlying
layer comprises a nonmagnetic metal material.

20

24. A method of manufacturing a thin film magnetic head
according to claim 22, further comprising forming a second
plated underlying layer on the protruding layer apart from
the first plated underlying layer, wherein at least the Gd-
25 determining layer is disposed between the first and second
plated underlying layers, the second plated underlying layer
comprises a magnetic material, and the lower magnetic pole
layer is formed on the second plated underlying layer by

plating.

25. A method of manufacturing a thin film magnetic head according to claim 15, further comprising partially forming a
5 third plated underlying layer on the Gd-determining layer, and forming the upper magnetic pole layer on the third plated underlying layer by plating.

26. A method of manufacturing a thin film magnetic head
10 according to claim 15, wherein the coil layer is formed on a plane parallel to the surface of the lower core layer so as to be wound around the back gap layer as a center.

27. A method of manufacturing a thin film magnetic head
15 according to claim 15, wherein the coil layer comprise a plurality of first coil segments formed in parallel to each other in the space surrounded by the lower core layer, the protruding layer and the back gap layer, and a plurality of second coil segments formed in parallel to each other on the
20 upper magnetic pole layer with an insulating layer provided therebetween, the first coil segments being non-parallel to the second coil segments; and

an end of each first coil segment and an end of each second coil segment face each other in the thickness
25 direction of the upper magnetic pole layer and are connected to each other through a connecting portion to form a toroidal coil structure.

(28. A thin film magnetic head as hereinbefore described,
with reference to the accompanying drawings.

29 A method of manufacturing a thin film magnetic head
5 as hereinbefore described, with reference to the accompanying
drawings.



INVESTOR IN PEOPLE

76

Application No: GB 0313691.8
Claims searched: All

Examiner: Ralph Cannon
Date of search: 27 October 2003

Patents Act 1977 : Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1, 2, 6, 13, 15, 16, 19, 26	US 20010013505 A1 (SASAKI) in particular figs. 33A, 34A and paragraphs 198-215.
X	1, 2, 13, 15, 16, 26	US 6154346 (SASAKI) figs. 25A, 30A, 32A, 46A and col. 12 line 50 - col 18 line 4.
X	1, 13, 15, 26	US 6191918 (CLARKE) figs. 3, 6K, 6L col. 4 line 34 - col. 5 line 64 col. 8 line 55 - col. 10 line 13
A		US 6417990 B1 (ZHOU) fig. 4A.
A		US 6259583 B1 (FONTANA) fig. 2, 6H, 6M

Categories:

X Document indicating lack of novelty or inventive step	A Document indicating technological background and/or state of the art.
Y Document indicating lack of inventive step if combined with one or more other documents of same category.	P Document published on or after the declared priority date but before the filing date of this invention.
& Member of the same patent family	E Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^y:

G5R

Worldwide search of patent documents classified in the following areas of the IPC⁷:

G11B

The following online and other databases have been used in the preparation of this search report:

Online: EPODOC, WPI, PAJ

THIS PAGE BLANK (USPTO)

**This Page is Inserted by IFW Indexing and Scanning
Operations and is not part of the Official Record**

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☐ BLACK BORDERS
- ☐ IMAGE CUT OFF AT TOP, BOTTOM OR SIDES
- ☒ FADED TEXT OR DRAWING
- ☒ BLURRED OR ILLEGIBLE TEXT OR DRAWING
- ☐ SKEWED/SLANTED IMAGES
- ☐ COLOR OR BLACK AND WHITE PHOTOGRAPHS
- ☐ GRAY SCALE DOCUMENTS
- ☐ LINES OR MARKS ON ORIGINAL DOCUMENT
- ☐ REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY
- ☐ OTHER: _____

IMAGES ARE BEST AVAILABLE COPY.

As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.

THIS PAGE BLANK (USPTO)